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Anedotical evidence suggests that the acknowledgments section tends to be most intensely read part of any given dissertation. Ironically, it typically gets written just days or even hours before the printing deadline, meaning that it doesn't get nearly as much attention of the author as the rest of the text. Fortunately, thanking people is far more simple than - and this is just a randomly chosen example - addressing endogeneity issues in econometrics.

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For completeness sake, I feel obliged to mention that the high proportion of luck I enjoyed in PhD committee composition was counterbalanced by being very,

[1] An analogy that defies any logical explanation. Yet, somehow it strikes me as being very accurate.

very unlucky in playing the lottery these past years[2]. In hindsight and without a whiff of irony, I'm glad it was not the other way around.

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[2] My lottery earnings over the past 4 years totaled 7.50 Euros, an awful performance.

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Introduction

In recent years, the European higher education sector has received increasing attention from policy makers and researchers. In the face of greying populations and the trend towards globalization, Europe shows an increased awareness about the crucial role of higher education in developing its knowledge economy. Given Europe's proximity to the world technology frontier, growth economists have pointed out that there is a growing need for highly-educated people and that it should therefore invest more in higher education (e.g. Aghion, 2006). Confronted with these high expectations, the higher educationsector faces tough challenges hindering the fulfillment of its role in providing education as well as carrying out research (an overview is provided by van der Ploeg & Veugelers, 2007). We touch upon some of the key challenges here, focusing upon those that tie in closely with the research questions addressed in this dissertation.

With respect to education, funding problems are one concern, if not the most important. On average, EU countries spend 1.3% of their GDP on the financing of tertiary education, compared to 3.3% in the US (OECD, 2006). The difference in the overall level of expenditures can be related to the way higher education is financed. The prevailing view on higher education in Europe is that the government provides education services as a public good, characterized by high subsidies and low tuition fees. Since public funds are limited and any increase primarily serves to keep up resources per student given rising enrolment rates, keeping higher education (nearly) free for students implies a clear spending limit. The restriction on private contributions exposes another issue, namely the over-regulation of European higher education institutions. Not only tuition fees but also decisions with respect to offering additional study programs are often subjected to centralized control. Finally, the often relatively small scale of European higher education institutions contrasts with their expanding array of responsibilities, such as dealing with increasing student numbers at bachelor level, carrying out high-quality basic research and commercializing scientific discoveries.

With respect to Europe's challenges in the realm of scientific research, evidence shows that Europe lags behind the US in both the volume and impact of research being done, controlling for population differences (Dosi et al., 2006). This raises the question what drives scientific excellence and how one stays at the forefront of knowledge production. The issue of making more efficient use of human capital not only pertains to the star scientists, but also to the less productive scientists, who, given their large share in the researcher population, represent an enormous potential for increased research output.

As a result of its recognized importance, the higher education sector itself has become the subject of intense study in order to gain a deeper understanding of the main challenges it is facing. We briefly indicate how this dissertation, consisting of four empirical studies, fits into a broader research agenda for higher education[3].

The first two essays deal with the education side and model the demand for (undergraduate) higher education. The results from these modeling efforts are used to simulate policy measures, in particular increased tuition fees and reduced supply. The first essay looks at the potential effects of increased tuition fees on participation, schooling decisions and welfare. These simulations offer concrete evidence in the discussion on both the appropriate level and differentiation of student's private contributions for their higher education. From an institutional perspective, the results also offer an insight in the consequences of relinquishing control of tuition fees by the government, handing it over as a decision variable to institutions instead. The second essay leverages the demand model by simulating unilateral cuts of study programs by colleges and universities and examining the effects on schooling decisions and welfare. This analysis relates to the efficiency debate and the challenge of reaching sufficient scale to cope with extending duties, mentioned above. The intricacies of providing the right incentives to institutions (from a wel-

[3] The largest Belgian research initiative that has looked into these issues in recent years is arguably the Interuniversity Attraction Poles project IAP P5/26, titled "Universities and Firms: A comparative Analysis of the Interaction Between Market Processes, Organizational Strategies and Governance" and carried out in 2003-2007. It was funded by the Belgian Science Policy and addressed a range of research themes in an interdisciplinary fashion. A new phase of the research project (IAP P6/09) will be carried out in 2007-2011 under the title "Higher Education and Research: Organization, Market Interaction and Overall Impact in the Knowledge-Based Era".

fare perspective) are demonstrated by analyzing one particular set-up of a funding scheme aimed at encouraging institutions to cut part of their supply.

The third and fourth essay deal with the research side, both presenting a model of research productivity at the level of the individual researcher. The skew output distribution triggers our interest in analyzing (persistent) top research performance and in characterizing the whole output distribution. Our analysis of star performance in the third essay contributes to the debate on the role of accumulative advantage in science. The fourth essay includes the "lesser Gods" in the analysis and compares the reasons that make researchers who display increasing levels of productivity write more papers or publish higher quality work. In both the third and fourth essay, the focus lies on career and "system" incentives like rank, additional funding, reduced teaching load, and other variables that make for interesting opportunities for policy intervention.

The overarching theme that connects the four essays is *excellence*, in the provision of education and in scientific productivity. We evaluate the performance of the higher education system in terms of participation and overall welfare, while research output is measured in terms of publications and citations.

The remainder of this introduction discusses the four essays that make up this dissertation in more detail. We clarify which question(s) each essay tries to answer, summarize the key findings and discuss the main limitations.

Excellence in Education

Essay 1: Participation and Schooling in a Public System of Higher Education

The first essay ties into the issue of higher education financing. As discussed above, students' private contributions cover only a marginal part of the true cost of their higher education. This essay contributes to the discussion whether public higher education systems may benefit from incorporating more market-oriented principles, such as increased tuition fees.

The analysis comprises two main parts. First, using a discrete choice model, we analyze the determinants of participation (whether to study) and schooling (where and what to study[4]) in the Flemish public system of higher education. Given the lack of variation in tuition fees, we focus on the impact of travel costs in pupils' decisions as a measure of their sensitivity to costs, whilst controlling for high school background and demographics. Second, using the estimates from the model, we simulate the effects of increased tuition fees. We look at the impact on both demand and welfare.

The dataset comprises all high school pupils in Flanders who completed high school in 2001 and are thus eligible to enter higher education. This group nearly fully covers the inflow into first-year undergraduate higher education, making this part of higher education an essentially closed system with virtually no students entering from outside the region. An essential component of the dataset is the detailed information on travel costs from pupils' homes to each higher education campus. This is complemented by basic demographics (viz. gender, nationality) and extensive information on prior schooling and ability (e.g. years of repetition in high school, type and religious affiliation of high school, high school education content area).

Determinants of participation and schooling decisions

The estimates of the demand model show that pupils perceive the available institutions and programs as close substitutes relative to the outside option: the nested logit approach allows inferring that travel costs hardly affect the participation decision i.e. demand for higher education is found to be very inelastic.

[4] A study option is defined on the basis of its location (campus), the type of higher education (academic -, long vocational - or short vocational programs) and the study field (e.g. biomedical sciences).

Conversely, travel costs are found to have a strong impact on schooling decisions. This ambiguous role of travel costs is the key finding arising from the demand model and plays a central role in the second part of our analysis where we simulate the effects of tuition fee increases on both participation and on total welfare.

Simulation of increased tuition fees

As a direct consequence of the parameter estimates, the estimated cost elasticities indicate that fee increases have a small effect on overall participation. This holds for both uniform fee increases as well as increases differentiated by type or study field. Differentiated fee increases represent a strong incentive for students to substitute towards the cheaper programs.

With respect to the welfare effects, we find that uniform cost-based tuition fee increases achieve most of the welfare gains whereas the additional gains from fee differentiation are relatively unimportant. These welfare gains are quite large under conservative assumptions on the social cost of public funds, and there is a substantial redistribution from students to outsiders.

A number of assumptions underlie these simulations of increased tuition fees, which are discussed here in terms of their impact on the results.

First, we assume that an introduction of increased fees would be accompanied by an income-contingent student loan system. Such a system avoids that students would not opt out of higher education because of difficulties to finance educational expenses in the face of increased fees. In the absence of such a system, the most capital-constrained students may drop out of higher education, implying a higher cost elasticity than estimated by the model. To the extent that low-income students are overrepresented in certain higher education programs, enrollment in these programs may suffer more from a given fee increase than attendance in other programs. Such an increased likelihood to substitute away from more expensive programs by lower-income students in principle leads to lower welfare than when students face no capital constraints, although this would depend on the precise substitution pattern.

Second, a progressive tax system does not distort the incentive to invest in higher education when assuming that students can deduct educational expenses from their future taxable income (Bovenberg & Jacobs, 2005; Jacobs & van der Ploeg, 2005). In other words, an substantially increased fee may influence the cost-benefit analysis of some prospective students to the extent where they decide to opt out of higher education. In absence of such a tax deductibility measure, we may therefore expect that the impact on participation as reported in the paper is underestimated.

Third, we assume that the private returns to higher education are equal to the social returns i.e. we do not include the social gains from higher education in our analysis. This assumption may impact the reported results in the sense that the negative impact on consumer surplus may generally be underestimated. For uniform fee increases, the small effect on participation suggests the bias is likely to be small, provided the size of these spillovers is modest. The scarce evidence on the existence of social returns indeed suggests that they are small (Jacobs & van der Ploeg, 2005). If one considers the implementation of non-uniform fee increases (i.e. varying over programs or study fields) and if positive spillovers are program-specific, then the bias may be more important. Specifically, given the sensitivity of students to costs in their schooling decision, increasing fees for programs with high(er) social returns will lead to a larger decrease in consumer surplus than our analysis measures.

Finally, we consider the government and the higher education institutions as an integrated entity. The underlying idea is that the government has full control over the higher education institutions so that the latter don't change the quality or diversity of their supply in response to an increase in fees. Using the variable subsidies per student as a proxy for the variable costs, this allows a simple producer surplus expression. In a more decentralized system where institutions could make their own decisions with respect to the number of programs they offer and where differentiated fees would strengthen reputation-based competition, the outcome of our analysis may be rather different. However, the maintained assumption does correspond to current reality where the government has a clear role in controlling diversity and quality of supply.

Essay 2: Reducing Supply Diversity in Higher Education

In this paper we analyze possible reforms in higher education from a different perspective. While the first essay looks into the effects of higher private contributions by students, the focus in the second essay turns to diversity in higher education supply. First and foremost, we analyze whether the supply of study programs in Flemish higher education has proliferated beyond what is socially desirable. A second question is whether a funding system containing a simple financial incentive, aimed at encouraging institutions to cut part of their supply, is effective in increasing overall welfare. This analysis was carried out amidst a funding system reform in Flanders and we analyze one of the incentives that was originally proposed as a key component of the new funding system which will enter in vigor on 1 January 2009.

This essay may be considered a natural extension of the previous one in the sense that it analyzes more drastic reforms than those considered in the first paper. While the first essay examines the effects of limited fee increases for a range of study programs, the second paper imposes a drastic increase in the fee of a study program, thereby driving demand for that program to zero. A key difference with the first paper is that we must now take into account the change in fixed costs: while we could abstract from fixed costs in the producer surplus calculation in the case of increased tuition fees, we must account for the fixed cost saving in the case of elimination of study programs. Since these costs are unobserved, we assume bounds on the fixed costs associated with study programs, which allows an unambiguous conclusion for the majority of currently offered study programs.

The analysis contains two main parts. First, we analyze the social desirability of unilateral program cuts by institutions. This analysis is based on the estimation of a demand model for higher education. The model extends the one in the first essay using a more detailed definition of study alternatives, allowing for a richer specification. We find that the social desirability of cutting programs at institutions is limited to less than 10% of the cases, due to the students' low willingness to travel and relatively limited variable and fixed cost savings. So with respect to their schooling decision students are very sensitive to travel cost and any reputation effects that may convince students to travel further are not sufficient to offset the strong preference for nearby options. Note that this finding is consistent with the analysis in the first essay, which also included the participation decision in the analysis and showed that pupils perceive the available institutions and programs as close substitutes *relative to the outside option*. Or, more informally, both essays find that students dislike traveling to more distant study alternatives, while the first essay adds that they dislike even more not studying at all.

Second, we contrast these welfare effects with the profit incentives given by a funding system that contains a rudimentary financial incentive to cut supply. We find that such a system, which closely resembles the originally proposed version of the new funding system for Flemish higher education, would often be off-target. In general, it gives an incentive to cut the smaller programs. However, we find that for the large part of supply where program cuts are undesirable, the system nevertheless encourages to cut at least one third of those programs. Furthermore, for the minority of cases where program cuts are actually desirable, we find it provides the wrong incentive for up to half of the cases. These findings emphasize the complexities in regulating the diversity of supply in higher education, and serve as a word of caution towards the various other measures that have recently been proposed.

Comments on the estimation of pupils' sensibility to costs

A key concern in our analysis is the reliability of the estimate of the travel cost parameter as an accurate measure of pupils' sensitivity to costs. Therefore, we go into the assumptions underlying the calculation of the travel cost variable and we discuss possible endogeneity issues.

We have defined an individual's annual travel costs as consisting of two components: the transportation cost and the opportunity cost of time, in line with Train & McFadden (1978). Our measure of travel cost embodies a number of assumptions. First, we assume a certain number of trips for a commuting student to attend the campus of her choice, viz. 10 trips/week during the 30 weeks of the academic year. We explicitly model a non-linear effect of travel cost on utility: students may go on residence, thereby reducing the number of trips in exchange for a rental cost.

Second, the transportation costs are based on a kilometer cost of 0.25 Euro, multiplied by the travel distance by road while the opportunity cost of time is based on a cost of 8 Euros/hour, multiplied by the road travel time. These assumptions allow the conversion of travel distance and travel time to an integrated cost measure, which permits a single parameter estimate reflecting pupils' cost sensitivity. While the kilometer cost is commonly used to quantify the cost of car travel, the value chosen to represent students' opportunity cost of time corresponds to the typical wage for student jobs. Together, these assumptions imply a certain rate of substitution between time and money. It may be argued that such a "one size fits all" does not capture individual heterogeneity in this trade-off: individuals may have idiosyncratic preferences for different means of transportation that imply a different trade-off between time and money, independent from influences like income, policy initiatives to promote public transport, etc. The estimated specification allows individuals to show a different sensitivity to travel costs depending on their individual characteristics, viz. gender, nationality, age, type and content of high school education. A particular concern with respect to the potential heterogenous impact of travel costs, is that students enrolled in different types of higher education[5] may reflect a different sensitivity to travel cost. Evidence that the estimated specification does pick up such differences in cost sensitivity is given by the cost elasticities[6]:

[5] I.e. academic -, long vocational - or short vocational programs.

[6] Also, split-sample regressions for the different types of higher education suggest a higher travel cost sensitivity for the students in short vocational programs compared to those in long vocational or academic programs.

there are examples of program fields with a similar market share that show different cost elasticities. For example, academic social studies students are more cost sensitive than vocational exact science students and vocational arts students are more cost sensitive than academic arts students. An extension of the model that would more fully account for individual heterogeneity is to estimate individuals' rate of substitution between time and money from the data, using for example a random coefficients model.

In general however, such differences in sensitivity to travel cost are likely to be the consequence of the endogeneity of travel costs. For example, unobserved income differences may translate into a different rate of substitution between time and money. Although we do not observe family income, alternative specifications were estimated including average income and unemployment rates at the level of the postal code, as a way to control for income effects. However, there appears to be too much variation in income at this aggregate level for these controls to be significant. It is important to note that the observed high school background variables[7] may capture substantial part of the variation in pupils' socio-economic backgrounds. For example, the estimates show that pupils from catholic high schools and those who had a classical languages and/or science education (within the general high school education type) are less cost sensitive, while pupils who had a technical high school education with a social orientation are more cost sensitive. As a result, the influence of socio-economic situation will be reflected in the estimates of the interaction terms. Any remaining endogeneity of travel costs due to income effects would be such that for lower income students the travel cost parameter will be overestimated.

Another source of endogeneity of travel costs besides income, is a student's social network at home: some students may have very strong ties to their social and family network at home compared to others, leading to the choice for more nearby higher education locations and an overestimate of the impact of travel costs.

[7] I.e. the type of high school (general, technical versus professional), the catholic versus non-catholic orientation of the school, the pupil's content area focus (e.g. classical languages).

Besides the true travel cost effect, social network- and income effects are likely to be important reasons for the observed preference for nearby study locations.

A final influence on road travel cost we want to point out, are policy initiatives to lower students' travel costs by means of cheap train tickets[8]. As a result, pupils' observed choices may reflect the availability of cheap rail travel[9]. Our estimate of the impact of travel cost on pupils' utility is then the combined effect of road travel cost and the compensating effect of rail travel.

Given these comments, what is the bottom line as far as the estimate of the travel cost parameter is concerned? Recall that, ultimately, our interest in the travel cost parameter is driven by the objective to simulate the impact of increased tuition fees on pupils' decisions. Given the lack of variation in fees across institutions or study programs we cannot directly estimate pupils' sensitivity to these fees. Therefore, we need another measure of pupils' sensitivity to higher education expenditures and we take pupils' responsiveness to travel costs as a proxy of their sensitivity to fees. Referring back to the preceding discussion, the issues of individual heterogeneity and endogeneity (due to the influence of income effects, social networks, cheap rail travel, etc.) may lead to inaccuracies in the estimate of the travel cost parameter. The fact that the estimate of the travel cost parameter may pick up the effect of cheap rail travel is a lesser issue: we are not interested in knowing the impact of *road* travel costs as such. Rather, we want to measure the effect of *incurred* travel costs, where these may include the use of other means of transportation. As discussed above, income and social network effects may introduce an upward bias for the travel cost estimate for subgroups of students. However, given the richness of the estimated specification that includes proxies for these socio-economic characteristics, the model may be expected to control to a large extent for these influences. A more conclusive answer to the question whether there is a difference in sensitivity in travel costs between students would require additional

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8 E.g. products like the students' rail ticket "Go-Pass" which charges students a fixed fee per trip i.e. independent of the distance traveled.

9 The role of train travel may also differ across the population, depending on individual preferences for advantages of rail travel vis-à-vis road travel such as the possibility for reading or social contacts

data to rule out omitted variable bias. Referring to the discussion above, indicators of the strength of students' ties to social networks back home would be the membership of sports clubs, youth associations, etc. This data could be recorded systematically in student registration records. Information about the envisaged means of transportation to campus could be collected at time of enrolment. Alternatively, information on actual modes of mobility may be gathered through the compulsory mobility surveys that not only large companies but also education institutions carry out bi-annually.

Excellence in Research

Essay 3: Top Research Productivity and its Persistence

The focus in this essay lies on the top end of the research productivity distribution: the star scientists. More specifically, our objective is to identify the factors that determine whether a researcher ever ends up in this "top league", and if she does, which variables explain whether she is able to repeat that top performance. By examining top performance in research productivity and its persistence over time, this paper contributes to the debate on cumulative advantage effects in academic research. The custom-built data set contains the publications of biomedical and exact scientists at the KU Leuven from 1992 till 2001 and allows taking into account factors like gender, age, cohort, rank, promotion, seniority, teaching load and access to research funding.

A consequence of our choice to focus on scientific excellence is that we need to separate the group of highly prolific researchers from the others, provided a meaningful distinction between the top group and the less productive scientists can be made. Therefore, we carry out a clustering of the researchers' yearly publication records distinguishing between three productivity categories (top, medium, low) while controlling for discipline and temporary gaps in research output. Given that the members of the resulting clusters differ significantly in their mean publication output, these discrete productivity categories give us meaningful thresholds to separate different productivity levels, which permits us to analyze entry into and exit from these different groups. In addition, these temporal productivity clusters allow a precise definition of what constitutes persistent top performance, viz. continuous membership of the top productivity category over time. Although one could argue that the underlying publication counts represent a richer source of information, it is not clear what part of the distribution represents the truly eminent scientists as opposed to "merely good" researchers. It is this discrete jump to star status that we are interested in, motivating the conversion of publication counts into discrete productivity clusters. We find that about one quarter of the scientists in the sample achieves top performance at least once in the observation period, with six out of a hundred scientists being persistently top. Using mobility matrices, we find that top productivity generally is persistent over time: previous top performers are more likely to reach top status in next periods.

We use the entry of a researcher into the top performance category to define the event of interest in the duration analysis, where we address the research questions discussed above. A hazard model predicting the time towards first top performance confirms the importance of gender, with females being significantly less likely to reach top performance. Age and seniority effects are not significant, but rank and hierarchical position, as well as access to excellence funding are important for explaining the hazard to first top performance. There is only limited evidence with respect to the substitution effect of teaching load on top research performance. Correction for scientific discipline, full time position and organizational membership is important. Low previous performers are less likely to reach top status, confirming that first top performance is a gradual, accumulative process, as the Matthew effect or a learning perspective would predict.

When analyzing subsequent top performances, we find strong support for the accumulative process, with the hazard to next top performance being significantly and increasingly positively affected by previous top performance. Rank is important not only in predicting first top performance, but also for persistency in top performance, supporting the accumulative effect. Also the gender bias remains significant in explaining subsequent top performance, but this time with the dependence on previous top performance in favor of females, suggesting that the gender effect is mainly a selection problem into first top. While funding and head of unit position are important for selecting into first top performance, they are less predictive for subsequent top performance. And finally, the correction for unobservable individual heterogeneity, like ability, is significant, suggesting that talent remains an integral part of the story of top performance and its persistence.

Essay 4: The Great Divide in Scientific Productivity. Why the Average Scientist Does Not Exist

Like the third essay, the starting point of our analysis is the skewness that characterizes scientific output, with a small number of scientists responsible for the lion's share of publications and citations. While the previous essay examined productivity determinants of (persistence in) scientific excellence, here we widen the scope and aim to characterize the whole productivity distribution. Although the skew distribution suggests substantial heterogeneity among researchers, previous work on scientific productivity has typically focused on explaining average productivity. This ignores the potentially strongly different impact of regressors at different points in the distribution. An example is the often observed "gender effect": male researchers typically publish more papers than female researchers, *on average*. This essay examines whether such effects operate evenly across the whole distribution, in which case a focus on average productivity alone would be justified, or whether they impact some points in the distribution more than others. In addition, we contrast effects on research quantity (using publication counts) with the impact of the same variables on research quality (using citation counts).

Our empirical approach uses quantile regressions to estimate the effects of age, gender, funding, teaching load and other observed characteristics of academic researchers on various locations in the distribution of publications and citations.

From a methodological point of view, two key issues should be noted. First, we employ recent advances in quantile regressions that allow its application to count data. Second, we account for unobserved heterogeneity of researchers by estimating a random-effects model, exploiting the panel nature of our dataset.

Estimation of the model using the same dataset as in the previous essay, i.e. a panel of biomedical and exact scientists at the KU Leuven in the period 1992-2001, shows strong support for the quantile regression approach, revealing the differential impact of various regressors along the distribution. Further, the results show that the magnitude of effects typically decreases towards the top of the distribution. This may be explained in terms of the predominance of talent as a key success factor at the high end of the distribution and/or may point to a progressive loss of incentive power with quantile for factors like funding, rank, etc. As far as the comparison of the quantity and quality distribution is concerned, we find that funding, teaching load and a scientist's entry cohort have a different impact on research quantity than on research quality.

Although one must be careful generalizing the results based on a single university, we argue that the findings are informative with respect to the management of scientists. In particular, they may instill the right expectations in administrators who implement incentive programs or make funding decisions. For example, our estimates indicate that a reduced teaching load for below-average productive researchers in an attempt to "pull them on board" is unlikely to lead to an envisaged increase in publications. The results with respect to funding suggest that, given the current funds distribution, there is a limit to the beneficial effects of competition in awarding research funds, strongly concentrating them into the hands of a just a few star scientists. While the top end of the distribution may face diminishing returns, research money flowing to the lower half of the distribution may be well spent given the sizeable effects on research output, both in terms of quantity and quality.

Chapter 1: Participation and Schooling in a Public System of Higher Education

Abstract

We[10] analyze the determinants of participation (whether to study) and schooling (where and what to study) in a public system of higher education, based on a unique dataset of all eligible high school pupils in an essentially closed region (Flanders). We find that pupils perceive the available institutions and programs as close substitutes relative to the outside option, implying an ambiguous role for travel costs: they hardly affect the participation decision, but have a strong impact on the schooling decision.

To illustrate how our empirical results can inform the debate on reforming public systems, we assess the effects of tuition fee increases. Uniform cost-based tuition fee increases achieve most of the welfare gains; the additional gains from fee differentiation are relatively unimportant. These welfare gains are quite large under conservative assumptions on the social cost of public funds, and there is a substantial redistribution from students to outsiders.

1.1 Introduction

Public systems of higher education are experiencing increased challenges in many European countries. The number of students has more than doubled over the past thirty years. Public spending increased at the same rate, because governments maintained very low tuition fees and high subsidies per student. Despite these large public investments, there seems no evidence that the public systems performed better than the more market-oriented systems in the Anglo-Saxon coun-

[10] This chapter is joint work with Frank Verboven.

tries.[11] This has lead to an increasing awareness that the public systems should incorporate more market-oriented principles. This is illustrated by the recent U.K. policy reforms to drastically raise tuition fees, accompanied with the introduction of income-contingent student loans.

Against this background we analyze the participation decisions (whether to study) and schooling decisions (where and what to study) of all eligible pupils in a public system of higher education. We focus on the role of travel costs, controlling for the pupils' high school background and demographics. We use our empirical results to analyze the effects of raising the tuition fees on both participation and total welfare.

Our empirical analysis is based on a unique data set of all high school pupils eligible to enter higher education in the essentially closed region of Flanders.[12] A first key feature of our data set is the information on the pupils' locations, from which it is possible to compute the travel costs to all available study options. A second key feature is the information on the educational choices at the highly disaggregate level of the study program. Our central empirical finding is that pupils perceive the higher education institutions and programs as close substitutes. This implies an ambiguous role for travel costs: college proximity hardly influences the participation decisions, but has a strong impact on the schooling decisions. Put differently, pupils are highly cost elastic regarding the decision where and what to study, but much less so regarding the decision whether to study.[13]

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[11] If anything, public systems appear to have performed worse than the private systems. Regarding educational performance, a frequently used measure is the student participation rate. According to the E.P.I. (Usher et al. (2005), participation rates tend to be lower in countries with lower private contributions (with the exception of Finland and the Netherlands). Regarding research performance, most top universities come from the more market-oriented Anglo-Saxon countries. Jacobs and van der Ploeg (2005) provide a detailed comparison of the relative performance of public and private institutions.

[12] Flanders is the Northern part of Belgium, where Dutch is spoken. While access is open, in practice the undergraduate system has been quite closed from the French-speaking part and from other countries. See for example van Heffen and Lub (2003) for an overview.

[13] Our empirical analysis also accounts for other choice determinants than travel costs. Most notably, we find an important role of high school background in both the participation and schooling decisions.

The effects of tuition fee reform on *participation* follow directly from our estimated cost elasticities.[14] A uniform tuition fee increase only has a small impact on overall participation, though comparatively more on pupils with a low-level high school background. Differentiated fee increases also have a small effect on overall participation, but they imply large substitution effects across institutions and/or study fields.

The effects of tuition fee reform on *total welfare* can be summarized as follows. (1) The total welfare gains from raising tuition fees are quite large if one accounts (in a conservative way) for the social cost of public funds, but small if one ignores that cost. (2) Uniform cost-based tuition fee increases achieve most of the attainable total welfare gains. The additional gains from cost-based tuition fee differentiation by program type or program field are surprisingly unimportant. (3) Tuition fee reforms imply a large redistribution from students to outsiders (who do not study). The overall conclusion is that uniform fee increases achieve most of the total welfare gains, as well as a fairer distribution between students and outsiders.

Previous empirical research has mainly looked at the effects of tuition fee on overall participation in higher education. These studies typically focus on the U.S. where it is possible to exploit tuition fee variation at the state level. Estimates on the participation effects of an increase in fees by \$ 1,000 are in the range of 3–8%; see Kane (1995), Dynarski (2003) and Cameron and Heckman (2001). We find a considerably lower participation effect of about 1%. This is perhaps not surprising since the current level of fees is low in the public system we consider.

Only few studies have looked at the effects of tuition fees at the level of the institution, and none at the more detailed level of the program field. Most closely related to our work is Long (2004), who conducted a comprehensive study on the role of tuition fees and travel costs at the level of the institution.[15] She first estimates a conditional logit model for the schooling decision (where to study) and

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[14] To identify the effects of tuition fees, we assume that pupils respond in the same way to tuition fees as to travel costs. We motivate this approach in our econometric framework (see section 1.3.2).

[15] Some other studies incorporated distance to college to explain the participation decision, see Rouse (1995) or Frenette (2003). However, with the exception of Long (2004) these studies do not observe which college the pupils actually choose, so that distance is usually proxied by the distance to the most nearby college (regardless of whether that college is actually chosen).

subsequently a binary logit model for the participation decision. Consistent with our own findings, she finds that tuition fees have a higher impact on the schooling than on the participation decision. We extend Long's model and analysis in several respects. First, we consider the participation and schooling decisions in a more general integrated nested logit framework. This approach allows us to infer the impact of tuition fees on both participation and schooling from variation in travel costs among pupils (in the absence of tuition fee variation in a public system).[16] Second, we consider the schooling decision at the even more disaggregate level of both the institution and the program field. Finally, we conduct a total welfare analysis on the effects of uniform and differentiated tuition fee increases.

The remainder of this paper is organized as follows. In the next section we discuss some key features of the higher education system in Flanders. This is representative for several other public systems of higher education, and it introduces our subsequent questions. In section 3 we introduce the empirical model of educational choice, and our estimation approach to handle the very large data set. The fourth section discusses the empirical results. We compare the estimates from our disaggregate nested logit model (at the level of the institution and study program) with those of aggregate logit and nested logit models (section 1.4.1). We also compute the estimated cost elasticities at various levels: total market level, colleges versus universities, and the four main program fields (section 1.4.2). Finally, we estimate the welfare effects of uniform and differentiated fee increases (section 1.4.3). Section 1.5 concludes.

1.2 The market for higher education in Flanders

We begin with a description of the supply and demand characteristics of the market for higher education in Flanders in 2001 (the year of our data set). We focus on the aspects that are relevant for the students' first-year decisions. At that point students

[16] We are able to compute the distance and travel costs of each pupil to each alternative based on information of the pupils' home address postal code, whereas Long (2004) only observes the pupils' high school address postal code.

essentially only consider the public (heavily subsidized) institutions, and almost always choose to study within the region of Flanders. The system is therefore essentially a closed public system of higher education, representative for many other European systems, but quite distinct from the U.S. system.

1.2.1 Supply of higher education

Institutions and programs

There are two types of higher education institutions in Flanders: colleges and universities. The colleges focus exclusively on teaching and offer vocational study programs, which are oriented to professional training. Universities are also active in research, and they offer academic study programs. Both colleges and universities either have a catholic or a non-catholic orientation. They sometimes have multiple campuses, especially the colleges.

The vocational programs offered at the colleges are either short programs (one cycle of 3 years), or long programs (two cycles comprising a total of 4 or 5 years). The academic programs at universities are always long programs (two cycles).[17] The programs can be divided into four fields: arts, social sciences, biomedical sciences, and exact sciences. Each field consists of several elemental study options, e.g. nursing (a vocational program in biomedical sciences) or civil engineering (an academic program in exact sciences).

Table 1.1 provides an overview of the supply of higher education in the year 2001-2002. The top panel shows the number of campuses, broken down by type of institution and program field. The total number of campuses is 53, the majority being college campuses (44 versus 9 university campuses). Colleges more often have a catholic affiliation, whereas universities more often have a non-catholic affiliation. Colleges show a higher degree of specialization, since they typically do

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[17] In recent years, the long vocational programs at colleges have shown a trend towards convergence to their academic counterparts at the universities (e.g. the economics or the engineering programs). This development has in part been stimulated by the government. Already in 1991, a Decree stipulated the same rules for two-cycle vocational programs at colleges as for academic programs at universities. Colleges offering two-cycle programs also became entitled to do applied research by means of co-operation agreements with universities. More recently, the Bologna Declaration leading to the Bachelor–Master reforms has strengthened these developments.

not offer all program fields. For example, only 12 out of the 44 college campuses offer arts. Universities tend to be less specialized. All non-catholic universities offer programs in biomedical and exact sciences, and all catholic universities offer programs in arts and social sciences.

The bottom panel of Table 1.1 shows the corresponding student numbers. The number of students is higher at colleges than at universities (25,182 versus 12,299). But the number of college campuses is comparatively even higher, so that the average scale at college campuses is generally lower than at university campuses. It is also evident that most students choose programs in social sciences, especially at the colleges, followed by programs in the exact sciences.

To give an idea of the geographic coverage of higher education supply across the region of Flanders, Figure 1.1 shows the locations of the campuses on a map. The upper map refers to the universities, the lower one to the colleges. Focus only on the circle areas for now. Each circle refers to a different campus, and is proportional to the number of first-year students. The figure shows that there is broad geographic coverage of higher education, with the exception of the "corners" in the West and in the East. However, this broad coverage is entirely due to the colleges. University coverage is concentrated around two main university cities (Ghent and Leuven).

The role of the government

As in most other European countries the undergraduate system of higher education in Flanders is entirely public. We only provide a very stylized overview here. Van Heffen and Lub's (2003) country report provides a more detailed description.[18]

Both universities and colleges receive subsidies for teaching; universities in addition receive subsidies for research. The subsidies for teaching consist of a fixed and a variable component. The variable subsidies differ across the various study programs to account for differences in the variable cost per student. According to CHEPS (Deen et al. (2005)), the cost per student tends to be lower for classroom-based programs (arts and social sciences) than for laboratory-based

[18] For shorter descriptions covering a large set of countries including the region of Flanders, we refer to Maassen (2000) or Eurydice (2000).

programs (biomedical and exact sciences). To account for this, the Flemish government has traditionally maintained a relatively simple system of four subsidy categories at colleges and three categories at universities. It has recently proposed to revise the rates to distinguish between additional categories, in line with the practices in seven benchmark countries.[19] Table 1.2 shows the (student-weighted) average variable subsidies per student, for the four program fields at colleges and universities. The first panel shows the averages using the current subsidy rates, the second using the proposed revised rates. The table shows that the subsidies, and hence the estimated variable costs per student, are lower in arts and social sciences than in biomedical sciences and exact sciences. They also tend to be lower at colleges than at universities. The proposed revised rates show a larger variation, especially across the different program fields.

The variable subsidies are only part of the government's "first flow" budget on higher education.[20] According to Cantillon et al. (2005), the total budget is about € 8600 per student, so that the variable part only accounts for about 38 percent of public spending. The remaining part is independent of the number of students and can be viewed as a measure of the fixed costs to be covered.

In addition to the subsidies, the government intervenes in the tuition fees that the colleges and universities are allowed to set. While the government gives some discretion, the tuition fees show hardly any variation in practice. During the year of our study, 2001, the tuition fees were essentially uniform at € 425 for colleges and € 445 for universities. This shows that private contributions are extremely low, only about 5% of public higher education spending (excluding research).

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19 These revisions fit in a larger policy reform proposal in 2005, which aims to transform the input-based subsidy system (based on the number of incoming students) to an output-based system (based on the number of outcoming students). To prepare these reforms, the input-based subsidies were frozen in 2000 and should become output-based in 2007. This development is not relevant for our purposes here; we are mainly interested in describing the variable subsidies as our proxy for how the goverment perceives the cost per student.

For a detailed description of the current (frozen) subsidy rates, see van Heffen and Lub (2003), and of the proposed revised rates, see Vandenbroucke (2005).

20 The first flow budget is the part of the budget that directly goes to teaching. The second flow and third flow budget are devoted to research.

The policy of high subsidies and low tuition fees may have adverse effects on both the diversity and the quality of the supply. First, colleges and universities may have incentives to offer too much diversity. The government therefore regulates the supply of programs. There is an official list of subsidizable programs, but not all institutions necessarily receive the authorization to offer all programs. The result is a specialization, which we illustrated earlier in Table 1.1. Second, the institutions may have limited incentives to provide sufficient quality. A system of quality assurance aims to provide sufficient incentives, through self-assessment and external visiting committees. In principle, the government can take away the authorization to offer a study program if quality is insufficient, though this rarely happens in practice.

1.2.2 Demand for higher education – summary statistics

We now discuss the demand for higher education. This also introduces our data set and subsequent econometric analysis of educational choice.

Every pupil with a high school degree is eligible to start with higher education. This is true regardless of the type of high school degree that has been obtained. There are three main types of high school degrees. A general high school degree provides a broad theoretical training as a basis to continue with higher education. A technical high school degree puts more emphasis on specialized technical-theoretic training but at the same time aims to provide a sufficiently general background to prepare for higher education. A professional high school degree focuses mostly on practical training. Pupils with a professional high school degree can still start with higher education provided that they have taken additional courses during a seventh year of study (so we only include those in our data).[21] In contrast with the U.S. and some other European countries, there is no direct rationing of participation in higher education, whether through *numerus clausus* or through minimum course

[21] There is also a fourth high school category, arts. This also offers a quite practical training. We do not exclude them from our analysis, but since there are relatively few pupils here we include them in our base category.

requirements or grades obtained during high school.[22] Each pupil who finishes high school is therefore in the position to make both the participation decision (whether to study) and the schooling decision (where and what to study) by selecting one option out of the full set of all available study alternatives.

To analyze this educational choice process, we combined two basic data sets, covering essentially the entire population of eligible pupils: a "pupils data set" of all 55,905 last year high school pupils in the year 2001; and a "students data set" of the 37,481 participating students.[23] For each pupil we observe sex, nationality, age, the high school institution, the high school degree (program), and the home address. The Appendix provides more detailed information on the two basic data sets, as well as on some additional auxiliary data sets, and how we combined them.

We constructed a number of relevant variables describing the pupils' profile, and we organize them in three groups. The first group consists of general demographics: sex, nationality and the religious affiliation of the high school. The second group contains the scholastic ability variables: years of repetition, the type of high school and the study program followed at high school. Years of repetition is the age minus 18, and measures the number of failures during high school. The type of high school (general, technical or professional) measures the intellectual background, as we discussed above. The study programs at high school offer additional information on ability and intellectual interests. For general high school, we distinguish among the following fields: classical languages, modern languages, economics, sciences and mathematics. These can be combined so they are not mutually exclusive. The brightest pupils often follow either classical languages or mathematics (or both). In technical high schools, there is a very large number of

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22 During the year of our study, some programs (e.g. engineering and medicine) indirectly limited the number of students through an entry examination. This does not function however as a mechanism to directly limit the number of students per year.

23 These are the pupils who either enroll immediately after highschool in 2001 (36,111 students) or with one year of delay (1,370 students). Because the number of students enrolling after one year of delay is so small, we decided not to include the even smaller numbers of students entering with further years of delay.

The total participation rate of eligible pupils is 67% ((36,111+1,370)/55,905). Note that the actual participation rate in higher education is lower since only 79% obtain of the people obtain a high school degree.

programs. For simplicity, we only distinguish between programs that are "people oriented" (e.g. beautician, interior design) and programs that are "product oriented" (e.g. car mechanics, construction techniques). There is also a large number of programs in professional high schools, but since there are relatively few pupils graduating from professional schools (and even fewer that start with higher education) we do not distinguish explicitly between programs for this category.

The third group of variables refers to transportation costs: distance travelled to the campus (in km), and time travelled either by road or by train (in min). Time travelled by road is the fastest calculated route from the pupil's home postal code to her chosen campus postal code. Time by train is equal to the travel time by road to the nearest well-connected train station, plus the travel time on the train, plus a fixed 10 minutes to incorporate the time to get from the destination station to the campus. Based on these variables, we also constructed an annual travel cost variable in monetary terms, for a student making 300 trips per year at a cost of € 0.25 per km and an opportunity cost of time of € 8 per hour[24]. This variable will enter our empirical model and it is further motivated at that point.

Table 1.3 shows the summary statistics: means for all the dummy variables (interpreted as fractions of the population), and means and standard deviations (in brackets) for the continuous variables. The first column shows the unconditional statistics, i.e. for all pupils. The remaining columns show the statistics conditional on the chosen alternative.

Demographics

Slightly fewer males than females graduated from a high school in 2001 (48%), and they are comparatively less likely to participate in higher education (45%). More surprisingly, male pupils are less represented in catholic institutions. This may be due to preferences, or to the different supply offered at catholic institutions; our subsequent empiral model distinguishes between these possibilities by accounting for the combined choice of institution and program fields. Similarly,

[24] The kilometre cost is a commonly used measure of distance cost for tax purposes (Belgisch Staatsblad (2006)). The opportunity cost of time is representative for the hourly wage of student jobs (Jobdienst KU Leuven (2006)).

pupils with a foreign nationality are less likely to participate (2% of the pupils is foreign, but only 1% of the students), and those who do participate are less represented at catholic institutions.

The majority of the pupils (75%) attended a catholic high school, and they are more likely to participate (78% of the students). Furthermore, students from a catholic high school are much more likely to choose a catholic institution (87% of the students at catholic institutions have a catholic high school background, compared to 75% in general). This suggests there are still strong links between the catholic high schools and the higher education institutions.

Ability

The average years of repetitions is 0.6 (with a large standard deviation of 1.06), but it is much lower for participating students (0.36) than for outsiders (1.11).[25] Among the students, the average years of repetition is especially small for students going to universities rather than colleges (0.16 versus 0.48).

Up to 48% of the pupils come from a general high school, slightly more than one third from a technical high school, and only 17% from a professional high school.[26] Pupils from a general high school are more likely to participate (they make up 60% of the students, and only 48% of the pupils). Pupils with a technical high school background are more or less proportionally represented in higher education, but they mainly participate at colleges, and only form a small minority at universities. Pupils from a professional high school (the base) are least represented.

Pupils with a general high school background in mathematics or classical languages have a particularly strong propensity to go to universities rather than to colleges or staying out. Pupils from a "people oriented" technical high school have a strong presence at colleges (over one third).

Mobility

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25 As mentioned earlier, for the pupils of a professional highschool, there is one additional preparatory year before becoming eligible to higher education. We include this in our definition of repetitions.

26 The total fraction of pupils in a professional highschools is much larger than 17%. However, a substantial number does not complete their degree, and we are looking here at last year pupils only.

Distance travelled is on average 35 kilometers, with a large standard deviation. Car and train travel time are on average 31 minutes and 48 minutes. The average annual travel costs (including transportation and time costs) is € 3,800. The average travel distance is higher for students going to universities than for students going to colleges (42 versus 31 km), reflecting the lower geographic coverage of universities as shown earlier on the map in figure 1.1. The rather high standard deviations show there is a lot of variation in distance travelled across students.

Our earlier Figure 1.1 provides additional information on the role of proximity to institutions in explaining participation. The different shadings shows the different participation rates throughout the region. Part (a) suggests that the university participation rates are related to proximity: high participation rates (above 25%) are especially found around the two main universities, whereas low participation rates (below 15%) occur in the West and East corners of the region. Part (b) also suggests that the college participation rates vary across the region according to college proximity. Nevertheless, the pattern is less pronounced, probably due to the high geographic coverage throughout the region. Note that the areas with little university participation are often areas with a high college participation (see for example the low university and the high college participation in the West). This suggests that proximity may not matter that much for the decision whether to study as for the decision where to study. Whether this is indeed the case, will be addressed in our econometric model.

These summary statistics provide some preliminary suggestive findings on the role of demographics, ability and mobility in participation and schooling decisions. We are now ready to discuss how our econometric framework takes these characteristics into account.

1.3 Empirical framework

We now specify the empirical model of the pupils' participation and schooling decisions, i.e. their decisions whether to start with higher education studies, and, if so, where and what to study. We model their decision in a discrete choice framework in which individuals choose the alternative that maximizes random utility among the set of available alternatives. We adopt a version of the nested logit model (McFadden (1978)). This model is well suited to deal in a reasonably flexible way with the very large size of our data set: $55,905$ pupils, 563 choice alternatives, and a large set of observed variables describing pupils and choice alternatives. In particular, the model allows for consistent estimation with a large set of choice alternatives, by explicitly aggregating and/or sampling over the alternatives. At the same time, the model incorporates unobserved heterogeneity since individuals may have correlated preferences across alternatives belonging to the same nest. More general models of unobserved heterogeneity, such as mixed or random coefficient logit models (McFadden and Train (2000)) inhibit sampling over alternatives and are therefore not feasible given the size of our choice set. Since we capture a lot of observed individual characteristics anyway, the need for more general models of unobserved heterogeneity is less than in other applications.

1.3.1 The choice model

Each individual i chooses one out of a large set of choice alternatives. The individuals are the pupils who have finished high school and who are therefore eligible to start with higher education studies. The choice alternatives are defined by the institution (the university or college) and the actual program (e.g. nursing, civil engineering, etc.) There is also one no-study alternative. The total number of choice alternatives is very large (563, including the no-study alternative), and it is typically not feasible to systematically incorporate observable choice-specific variables at this level of detail. Our framework therefore explicitly deals with the possibility of aggregation and sampling over alternatives.

There are J study options, $j = 1 \cdots J$. For each study option j there are K_j variants or “elemental alternatives”, $k = 1 \cdots K_j$. Alternative 0 is the no-study option. The total number of alternatives is $\sum_{j=1}^{J} K_j + 1 = 563$. The empirical analysis aggregates the K_j variants to the level of the study option j. For example, the study option may be defined at the level of the institution, or at the level of the institution, program type (short vocational, long vocational or academic) and program field (arts, social sciences, biomedical sciences or exact sciences). In both cases, the variants per study option are defined accordingly, i.e. as the actual programs offered under the defined study option. Note that this framework also covers the general case of no aggregation: simply define the study options as the institution and the actual program. Each study option then goes with a single variant, so that $K_j = 1$ for all j.

An individual i's utility for study option j and variant k, U_{ijk}, is the sum of a deterministic component V_{ijk} and a random component ε_{ijk}, i.e. $U_{ijk} = V_{ijk} + \varepsilon_{ijk}$. Assume that there is no choice-specific information at the level of the variant k. Hence, the deterministic component of utility is the same for each variant k of study option j, $V_{ijk} = V_{ij}$ for all k. Individual i's utility for study option j and variant k is then given by:

$$U_{ijk} = V_{ij} + \varepsilon_{ijk}.$$

Individual i's utility for the no-study option is:

$$U_{i0} = V_{i0} + \varepsilon_{i0}.$$

The random component of utility follows the distributional assumptions of a three-level nested logit model (McFadden (1978)). At the highest level, there are two nests: the study nest S, which includes the study options and their variants; and the no-study nest, which is a degenerate nest with only alternative 0. At the lower level, the study nest S consists of the J different study option nests, $j = 1 \cdots J$. At the lowest level, each study option nest j consists of the K_j variants. The distribution of the ε_{ijk} and ε_{i0} has a sequential structure with two parameters, ρ and σ. The parameter ρ roughly measures the extent to which the ε_{ijk} show correlation between the J study option nests within the study nest S (i.e. correlation relative to the no-study option 0). Similarly, the parameter σ measures the extent to which the ε_{ijk} show additional correlation across the K_j variants within a given study option nest j.[27] A parameter close to zero means that the correlation is weak,

[27] There is no parameter for the no-study nest, since it is a degenerate nest. Furthermore, we

while a parameter close to one means that the correlation is strong. To illustrate, if $\rho = \sigma = 0$ the model reduces to a simple logit model with no correlation between the ε_{ijk}. As another example, if $\rho = 0$ and $\sigma = 1$, then there is no correlation of the ε_{ijk} between the study option nests, while there is perfect correlation between the variants within each study option nest.

Individuals choose the alternative that maximizes random utility U_{ijk}. The nested logit model is consistent with random utility maximization if $0 \leq \rho \leq \sigma \leq 1$ (McFadden (1978)), i.e. correlation parameters are between zero and one, with a weaker correlation between than within the study option nests. Because the distribution of the ε_{ijk} and ε_{i0} has a sequential structure, the nested logit model yields simple expressions for the conditional choice probabilities: the probability of choosing a variant k within a study option nest $P_{ijk|j}$, the probability of choosing a study option j within the study nest $P_{ij|S}$, and the probability of choosing the study nest P_{iS}. We are not interested in the probability that individual i chooses variant k of study option j, i.e. $P_{ijk} = P_{ijk|j}P_{ij|S}P_{iS}$, since there is no choice-specific variation at the level of the variant k, $V_{ijk} = V_{ij}$. Our interest is thus only in the aggregate probability that individual i chooses any variant of study option j, i.e. $P_{ij} = P_{ij|S}P_{iS}$. Applying the formulas for the three-level nested logit model, the probability P_{ij} for $j = 1 \cdots J$ is:

$$
\begin{aligned}
P_{ij} \quad = \quad & \frac{\left(\sum_{k=1}^{K_j} \exp(V_{ijk}/(1-\sigma))\right)^{\frac{1-\sigma}{1-\rho}}}{\sum_{j=1}^{J}\left(\sum_{k=1}^{K_j} \exp(V_{ijk}/(1-\sigma))\right)^{\frac{1-\sigma}{1-\rho}}} \\
& \cdot \frac{\left(\sum_{j=1}^{J}\left(\sum_{k=1}^{K_j} \exp(V_{ijk}/(1-\sigma))\right)^{\frac{1-\sigma}{1-\rho}}\right)^{(1-\rho)}}{\left(\sum_{j=1}^{J}\left(\sum_{k=1}^{K_j} \exp(V_{ijk}/(1-\sigma))\right)^{\frac{1-\sigma}{1-\rho}}\right)^{(1-\rho)} + \exp\left(V_{i0}\right)}.
\end{aligned}
$$

assume that the parameter σ is common for all J study option nests. It would be straightforward to allow this parameter to vary across the study option nests, e.g. according to the institution or program type or program field.

Since the variants k within study option nest j have the same utility, $V_{ijk} = V_{ij}$ for all k, this can be simplified to:

$$P_{ij} = \frac{\exp(V_{ij}^*/(1-\rho))}{\sum_{j=1}^{J} \exp(V_{ij}^*/(1-\rho))} \frac{\left(\sum_{j=1}^{J} \exp(V_{ij}^*/(1-\rho))\right)^{(1-\rho)}}{\left(\sum_{j=1}^{J} \exp(V_{ij}^*/(1-\rho))\right)^{(1-\rho)} + \exp\left(V_{i0}\right)}, \quad (1.1)$$

where $V_{ij}^* = V_{ij} + (1-\sigma)\ln(K_j)$ can be interpreted as the aggregate utility of a study option j. This shows that we can consider a simplified two-level nested logit model at the level of the study option j, after simply including $\ln(K_j)$ as a correction term to V_{ij}; see also Ben-Akiva and Lerman (1985). The correction term captures the extent of unobserved heterogeneity within a study option. It drops out if $(1-\sigma)$ is equal to zero: the utilities of the variants of the same study option are perfectly correlated (homogeneous), so that additional variants do not lead to a higher aggregate utility of that study option. Note that the correction term also drops out in the general case of no aggregation, since in this case $K_j = 1$ for all j.

The probability that i chooses the no-study option P_{i0} is simply:

$$P_{i0} = 1 - P_{iS} = \frac{\exp(V_{i0})}{\left(\sum_{j=1}^{J} \exp(V_{ij}/(1-\rho))\right)^{(1-\rho)} + \exp\left(V_{i0}\right)}. \quad (1.2)$$

It is instructive to compare this model to Long (2004), who has been the only other author to consider the study options at the level of the individual institution. First, she does not include a correction term $(1-\sigma)\ln(K_j)$ to the utility terms of the study options. This is a special case of our model if $\sigma = 1$, i.e. homogeneity of the variants within the institution. Second, Long estimates her model sequentially. In a first step, she models the probability where to study, conditional on choosing to study, i.e. $P_{ij/S}$ in our notation. In a second step, she models the probability whether or not to study, i.e. P_{iS} and P_{i0}, using the characteristics of the predicted most preferred alternative as explanatory variables in the deterministic component of utility. This may also be viewed as a special case of our model for $\rho = 1$. Indeed, as ρ goes to one, we have $(1-\rho)\ln\left(\sum_{j=1}^{J} \exp(V_{ij}^*/(1-\rho))\right) = \max(V_{i1}^* \cdots V_{iJ}^*)$, so that P_{iS}, as given by the second part of (1.1), reduces to Long's binary choice model.[28] Equation (1.2) under the special case of $\rho = 1$ is also essentially the modeling approach followed by Rouse (1995) and Frenette (2003), since they consider the participation decision as a function of the closest college in a binary logit framework.

1.3.2 Indirect utility

We specify the deterministic component of utility V_{ij} of individual i for alternative j as a conditional indirect utility function. It depends on the expected benefits, including monetary returns in the form of increased future salaries, and on the expected costs, i.e. the non-monetary costs of studying and the monetary costs in the form of tuition fees and travel costs. In our application, tuition fees are low and do not show any variation across alternatives. However, individuals pay an implicit price in the form of travel costs: transportation costs and the opportunity cost of time. We consider the following specification of V_{ij}:

$$V_{ij} = \beta_j + w_i' \gamma_j + \alpha_i (y_i - t_j - g(x_{ij})), \tag{1.3}$$

where w_i is a vector of individual characteristics (sex, age, high school background, etc.), y_i is individual i' s annual income, t_j is the tuition fee for study option j (currently uniform at about € 500 for all $j \neq 0$, but possibly differentiated across study options after tuition fee reform), and $g(x_{ij})$ is the implicit price paid by individual i for alternative j, which is a function of the annual travel costs x_{ij}.

The first and second terms in (1.3) refer to the intrinsic utility of each alternative j. In principle, one may include a full set of alternative-specific intercepts β_j and slope vectors γ_j, which are interacted with the individual characteristics vector w_i. In practice, such flexibility would imply a very large number of parameters to be estimated. We will therefore summarize the alternative-specific effects β_j and γ_j by a more limited set of characteristics, i.e. the institution's religious orientation, the program type and the program field.

[28] This comparison is not entirely accurate. Long's specification includes variables such as distance in both steps of the estimation. For her approach to be exactly a special case of our random utility framework, the coefficients of these common variables should have been restricted to be the same.

The third term in (1.3) refers to the utility derived from the consumption on other goods (i.e. other than the educational choice), after spending the tuition fee t_j and an implicit price $g(x_{ij})$, which is an increasing function of the annual travel costs x_{ij}. The parameter α_i can be interpreted as the marginal utility of income of individual i. It can be used to reinterpret the magnitudes of the other parameters such as the γ_j in (1.3) in monetary terms (by simply dividing γ_j by α_i), and to conduct a more complete welfare analysis.

The annual travel costs x_{ij} of individual i for alternative j consist of two components: transportation costs and the opportunity cost of time (McFadden and Train (1978)). The transportation costs (in Euro) are proportional to the distance per trip d_{ij} (in km). The opportunity cost of time (also in Euro) is proportional to the travel time per trip t_{ij} (in min). More precisely, specify the annual travel costs as $x_{ij} = 75d_{ij}+40t_{ij}$.[29] Each individual has two options: commute or go on residence. If she commutes, her implicit price for alternative j is simply $g(x_{ij}) = x_{ij}$. If she goes on residence, she saves a fraction ϕ of the trips, but pays an extra annual cost on rent r_j. Her implicit price is correspondingly $g(x_{ij}) = (1-\phi)x_{ij} + r_j$. A cost-minimizing individual commutes if $\phi x_{ij} \leq r_j$, and goes on residence otherwise. Intuitively, commuting is preferred if the annual travel costs are sufficiently small relative to the annual cost of rent. The deterministic component of utility (1.3) for a cost-minimizing individual can then be written as:

$$V_{ij} \;=\; \beta_j + w_i'\gamma_j + \alpha_i\,(y_i - t_j - x_{ij}) + \alpha_i(\phi x_{ij} - r_j)\,I(\phi x_{ij} - r_j), \qquad (1.4)$$

where $I(\cdot)$ is an indicator function equal to 1 if the expression inside the brackets is positive, and equal to 0 otherwise. Utility thus decreases in the travel costs x_{ij} in a piecewise linear way: at a steeper rate α_i for low values of x_{ij} (when the pupil commutes), and at a flatter rate $\alpha_i\phi$ for high values of x_{ij} (when the pupil goes on residence).

[29] This assumes that a commuter engages in 10 trips per week during 30 weeks of the year, at a transportation cost of 0.25 Euro/km and an opportunity cost of time of 8 Euro/hour. The latter amount corresponds to the typical wage for student jobs (Jobdienst KU Leuven, 2006) and was subjected to a sensitivity analysis. The annual transportation cost per kilometer (in Euro) is then $10 \cdot 30 \cdot 0.25 = 75$, and the annual opportunity cost of time per minute (in Euro) is $10 \cdot 30 \cdot (8/60) = 40$.

The utility specification (1.4) holds for the J study options, $j = 1 \cdots J$, as well as for the no-study option 0. For the study options, x_{ij} has the clear interpretation of the travel costs of individual i to study option j. This may clearly vary across individuals and study options. For the no-study option, x_{i0} can be interpreted as the travel costs to work. We assume this to be constant across individuals, $x_{i0} = x_0$, and to be sufficiently small so that the last term does not enter in V_{i0}.[30]

It is again instructive to compare this specification to Long (2004). She allows utility to vary quadratically with distance, and finds that utility decreases with distance at a decreasing rate. Our commuter/resident specification yields the same degree of flexibility. In fact, a specification of V_{ij} that is quadratic in x_{ij} indeed gave a similar fit. The advantage of our approach in this context is that the coefficient of x_{ij}, i.e. α_i, can also be interpreted as the marginal utility of income. This is useful since unlike Long we cannot identify α_i through direct price variation (since t_j is currently uniform across alternatives). In sum, our specification allows us to capture the role of distance in the same flexible way as Long's, while at the same time enabling us to estimate a marginal utility of income coefficient in the absence of any direct price variation.[31]

1.3.3 Estimation

The choice probabilities (1.1) and (1.2) may be used to construct the likelihood function and estimate the model. There are, however, practical difficulties due to the size of our data set.

- There is a very large number of individuals ($55,905$).
- Each individual can choose from a very large number of alternatives (563, including the no-study alternative).

[30] The exact value of x_0 is irrelevant and can be normalized since it is not separately identified from β_0.

[31] Identification of the tuition fee effect is thus based on the assumption that individuals respond in the same way to tuition fees as to travel costs. This approach has been frequently followed in applications where prices are zero, or show little or no variation. See for example Hausman, Leonard and McFadden (1995). In our application, this approach is reasonable to the extent that capital constraints are not binding.

- The associated choice-specific variables need to be interacted with many individual characteristics (the demographic and high school background variables).

There are several ways to reduce the size of the data set: aggregation over alternatives, sampling over alternatives, and sampling over individuals. We adopt a combination of these approaches.

First, we aggregate over alternatives. Using the framework in section 1.3.1, we aggregate the variants k to the level of the study option j by adding the correction term $(1-\sigma)\ln(K_j)$ to V_{ij}. We consider two definitions of the study option j. Our "aggregate" model defines the study options as the 53 different campuses. This model serves as a useful benchmark since it considers the same aggregation level as in Long (2004). It discards, however, almost all of the information on the study programs (except for including the correction term for the number of programs offered at the institution $\ln(K_j)$). Since this is a main source of richness of our data, which we want to exploit in our empirical analysis, we will focus on a "disaggregate" model. This model defines the study options as the 154 different campuses, program types, and program fields (though it still aggregates over the actual programs within a field, e.g. nursing which is one of the vocational social sciences programs). Utility V_{ij} can then be specified to depend on both the institutions' characteristics and on the program characteristics down to the level of the program field.

Second, we sample over alternatives; this is only necessary to estimate our disaggregate model. In simple logit models one can randomly select a reduced choice set for each individual, and define the choice probabilities as if the individuals only faced this reduced choice set. Maximum likelihood estimation based on these as-if choice probabilities yields consistent estimates (McFadden (1978)). We extend this approach to the nested logit model by exploiting its sequential structure. We first consider the probability of choosing a study option j, conditional on choosing to study, i.e. $P_{ij|S}$ entering as the first term in (1.1). This is a simple logit probability, so that it is possible to sample over alternatives and obtain consistent estimates. More precisely, for each student we construct a reduced choice set of 20 study options, i.e. the chosen study option and a random sample of 19 other study options. This gives consistent estimates for the parameters entering the study option utilities V_{ij}. We subsequently consider the probability whether to study, i.e. $P_{i|S}$ entering as the second term in (1.1). Provided that the utilities of all the study options are now included, as computed from the parameter estimates of the first stage, this yields consistent estimates of the parameters entering the no-study option V_{i0} and of the distributional parameter ρ. Since this is a two-step estimation procedure, the standard formulas for the standard errors of the parameters computed in the second step (i.e. those for the no-study option and ρ) are not correct. We follow the general procedure of Murphy and Topel (1985) to obtain the corrected standard errors.

Finally, we sample over individuals. In general, there is a trade-off between sampling over alternatives and sampling over individuals (doubling the size of the sampled choice set implies halving the number of individuals to keep the size of the data set fixed). Our experience showed that it is more efficient to sample over the alternatives than over the individuals, in particular to identify the utility effects of some relatively unpopular alternatives with few observations. We therefore sampled much less heavily over individuals than over alternatives. For both the aggregate and the disaggregate models we sampled about $20,000$ out of the $55,905$ individuals, as compared to a sampled choice set of 20 out of the 155 alternatives.

1.3.4 Alternative specifications

We compare three different models.

- In the aggregate logit model the choice alternatives are at the level of the institution. The choice set thus consists of 54 alternatives, i.e. 53 study options and one no-study option.
- In the aggregate nested logit model the choice alternatives are again at the level of the institution, but there is now a nesting parameter ρ that may be

different from 0. This allows for unobserved heterogeneity in that individuals may have correlated preferences across the 53 study options, even after conditioning on the observable characteristics.

- In the disaggregate nested logit model the choice set consists of 155 alternatives (including one no-study option), referring to the institutions, the program types (long and short vocational, and academic) and the program fields (exact sciences, biomedical sciences, social sciences and arts). There is again a nesting parameter ρ to allow for correlated preferences across the 154 study options.

The first two specifications correspond to the previous literature, which also looked at the participation and schooling decisions at the aggregate institution level. As mentioned earlier, there are still two important differences with the most comprehensive study to date, i.e. Long (2004): the inclusion of the correction term $\ln(K_j)$ to account for the aggregation over the different programs within each institution; and the integrated consideration of the participation and schooling decisions. The third specification is at the more detailed level of the institution and the program field, which has not been considered in previous work. Since this third specification is the most general, we will focus our discussion around it, and use the results from the two aggregate models mainly as a point of comparison with previous work.

It remains to specify the variables entering the indirect utility V_{ij} as given by (1.4), i.e. the individual characteristics entering w_i and α_i, and the choice characteristics entering β_j and γ_j. The vector of individual characteristics w_i includes the following 12 variables: sex, nationality, years of repetition during high school (age $-$ 18), high school's religious orientation (catholic or not), and 8 variables referring to the type of high school education (i.e. various forms of general and technical high school, relative to a professional high school education). Similarly, we specify the marginal utility of income or the travel cost parameter α_i to depend on the full vector of individual characteristics w_i. Hence, $\alpha_i = w_i'\alpha$, where α is the corresponding vector of parameters.

The number of alternative-specific intercepts β_j and slope vectors γ_j is very large. In particular, in the disaggregate model with 155 choice alternatives and 12 individual characteristics in w_i, there are up to $154 + 154 * 12 = 2002$ parameters to be estimated. To make estimation and interpretation feasible, we therefore put some structure on β_j and γ_j. The intercepts β_j are specified to depend on a full set of institution, program type and program field dummy variables. The slope γ_j^l corresponding to each individual's characteristic l depends on the following choice characteristics: a dummy variable for the no-study option (γ_0^l), and a set of dummy variables characterizing the study options: the religious affiliation of the institution (catholic or not), the program type (short-term vocational, long-term vocational or academic) and the program field (exact sciences, biomedical sciences, social sciences, or arts). We take the following study option as the base: a non-catholic institution offering a short-term vocational program in the field of arts. Hence, all estimated slopes γ_j^l should be estimated relative to that base.[32]

Descriptive statistics on the individual characteristics entering w_i and α_i, unconditional and conditional on the chosen alternative, were presented and discussed earlier in Table 1.3.

1.4 Empirical results

We begin with a discussion of the parameter estimates, to uncover the determinants of the participation and schooling decisions. Next, we summarize our key results through the cost elasticities implied by our estimates. Finally, we draw some implications on the welfare effects of uniform and differentiated tuition fee increases.

[32] In the two aggregate models with 54 alternatives, the number of alternative-specific intercepts β_j and the alternative-specific slopes γ_j is lower, i.e. $53 + 53 * 12 = 702$, so that estimation of all parameters would be easier. However, for ease of comparison and interpretation we adopt a more parsimonious specification that is similar to the disaggregate model. The only difference is that the β_j and γ_j obviously no longer include dummy variables referring to long-term vocational program type and to the program fields.

1.4.1 Parameter estimates

Tables 1.4 and 1.5 present the empirical results. Table 1.4 compares the estimates of several parameters across the three different models (aggregate logit, aggregate nested logit, and disaggregate nested logit): the nesting parameters ρ and σ, the slope parameters entering the utility of the no-study option (γ_0) and the travel cost parameters (α). Table 1.5 shows the slope parameters entering the utility of the study options (γ_j, $j \neq 0$). This table only shows the estimates for the disaggregate nested logit model, since there are many of these parameters.[33]

We first discuss the observed and unobserved determinants of participation (γ_0 and ρ in Table 1.4). Next, we highlight the role of mobility costs in both participation and schooling (α in Table 1.4). Third, we discuss the determinants of schooling (γ_j, $j \neq 0$ in Table 1.5). Finally, we briefly discuss the aggregation parameter (σ in Table 1.4).

Observed and unobserved determinants of participation (γ_0 and ρ)

The top part of Table 1.4 shows how individuals differ in their valuation of the no-study option. We focus our discussion on the estimates of the most general disaggregate nested logit model (third column). Males and especially foreigners have a significantly higher utility from staying out of higher education. The same holds true for older pupils, i.e. those who experienced repetitions during high school. Pupils from a catholic high school have a significantly lower utility from staying out than others. This is consistent with the reputation of the catholic high schools in providing a strong preparation for a higher education.

The most important individual characteristics affecting the participation decision relate to the pupils' type of high school. Pupils with a technical and especially those with a general high school education have a substantially lower utility from staying out relative to the pupils from a professional high school. This may be either due to the acquired or due to the intrinsic skills of these pupils. So one should be cautious and not conclude that promoting general high school education will

[33] A comparison of the parameters in γ_j across models does not yield any main additional insights. Many of the parameters do not enter in the aggregate models, and the ones that do (relating to the institutions' religious affiliation and program type) were usually estimated to be similar.

improve participation in higher education. What matters for our purposes, is only that the type of high school background does play an important role, which will be reflected in our estimated cost elasticities. Finally, while the type of high school plays a crucial role, the specific discipline followed at the high school does not matter much in the participation decision. None of the so-called more difficult general high school disciplines, such as mathematics or classical languages, matter in the participation decision.

Most of the estimated γ_0 are of a similar order of magnitude in the more restrictive aggregate models, but there are some important differences. For example, the aggregate logit model estimates pupils with a catholic high school background to have a higher utility from staying out, in contrast with common wisdom. This illustrates the importance of accounting for unobserved heterogeneity affecting the participation decision, as captured by the nesting parameter ρ. While the logit model restricts ρ to be equal to zero, the nested logit model estimates it as 0.90 and 0.95 in the aggregate and disaggregate versions. Hence, pupils have strongly correlated preferences across all study options and view them as close substitutes relative to the no-study option.[34]

In sum, while several observed individual characteristics affect the utility of the no-study option, there remains a lot of unobserved heterogeneity affecting the participation decision.

The role of mobility costs in participation and schooling (α)

The next question concerns the role of the annual travel costs, affecting the valuations of the study options relative to the no-study option. Table 1.4 shows that the annual travel costs have a negative and highly significant effect on utility (an estimate of -6.46 and a t-statistic of -17.84 in the third specification). Furthermore, the parameter $\phi = 0.49$ shows that the effect of travel costs is not linear but decreasing. Students who live sufficiently far and go on residence save 49% on the travel costs (to be traded off against their fixed renting costs). The effect of the travel costs differs across individuals in some respects, for example pupils

[34] The parameter is significantly different from one at the 5% level, so that perfect correlation can be rejected.

from a catholic high school are somewhat less cost sensitive. Pupils from a technical high school with a social orientation appear to be more cost sensitive than others. Overall, however, mobility costs do not show much significant variation across individuals.

Travel costs thus have a highly significant effect, but do they play a quantitatively important role in the pupils' participation decision? Or are they more relevant for the schooling decision, i.e. the decision where and what to study? Since the travel costs enter the utility of the no-study option and the study options with a common parameter α_i, it would appear that they may have a similar effect on both the participation and the schooling decisions. However, this is only the case in the logit model. The nested logit models showed that pupils value the various study options as close substitutes for each other, relative to the no-study option. Our estimate of $\rho = 0.95$ implies that pupils are actually up to $1/(1 - 0.95) = 20$ times more responsive to travel costs in their schooling decision than in their participation decision (see (1.1)). An increase in the mobility costs of one of the study options would thus generate substantial shifts in demand to other study options. But an increase in the mobility costs of the no-study option would have much smaller effects. In this sense, the pupils' mobility is a relative matter. Most pupils choose a study option close to their homes because they have a lot of study options in their neighborhood and they view these as close substitutes to more distant alternatives. But those pupils who do not have nearby access to any study option, would be willing to travel high amounts. These findings will be confirmed in our subsequent analysis, where we report the cost elasticities implied by our estimates.

Determinants of schooling (γ_j)

Table 1.5 shows how individuals differ in their valuations of the various study options. The base study option is a non-catholic institution offering a short-term vocational program, in the field of arts. To obtain an idea of the quantitative importance of the parameter estimates, one may compute the additional willingness to pay relative to the base study option in monetary terms (in € 10,000's), by simply dividing the coefficients by the marginal utility of income α_i. Table 1.5 reveals several interesting findings.

The first column shows how individuals value catholic institutions of higher education. Few variables play a role, but the one exception is the religious orientation of the pupil's former high school. The coefficient of 1.05 is highly significant and it is also quantitatively important. It amounts to an additional willingness to pay for a catholic institution by pupils from a catholic high school of € 10,000 $\times$ 1.05 / (6.46-0.45) = € 1,750. This indicates that there are still strong linkages between the religious networks.

The next two columns show the valuations for the program type, i.e. academic or long term-term vocational programs (relative to short-term vocational). Interestingly, males and foreigners have a higher valuation for academic or long-term vocational programs. Hence, while they have a lower utility from participation (as we saw before), they do have a stronger preference for the long-term programs conditional on participating. Pupils who experienced years of repetition during high school have a lower utility from participating in the long-term programs, whether vocational or academic. The type of high school plays a significant role: pupils with the intellectually more demanding general high school background are not only more likely to participate, but they also choose the more demanding vocational long and especially academic program types. Their additional willingness to pay for academic programs at universities than for short-term vocational programs at colleges amounts to €10,000 $\times$ 2.71 / (6.46-0.36) = € 4,440. Furthermore, while we earlier found that the specific discipline taken at a general high school does not matter for participation, it does matter for the type of higher education program. Pupils with a general high school background in science, mathematics and classical languages have a substantially higher valuation for the academic or long-term vocational programs than for the short-term programs. Most notably, pupils who took classical languages would be willing to pay an additional € 10,000 $\times$ 1.88 / (6.46-0.53) = € 3,170 to follow an academic rather than a short-term vocational program, relative to comparable other general high school pupils.

The final three columns show the valuations for the specific program fields. The type of high school and the specific discipline followed at high school play the quantitatively most important roles. Generally speaking, pupils prefer the program fields that closely match the discipline they followed at high school. For example, pupils who followed science or mathematics at a general high school prefer sciences, whereas pupils who followed classical languages prefer arts. These findings stress the central importance of the high school background in the subsequent higher education decision, in contrast to some claims that the general high school leaves the options open for all study options at the higher education level.

It is interesting to point out that the gender effect also comes out strong in explaining differences in valuations across the study fields. Females have a strong preference for arts and especially biomedical sciences, and the weakest preference for exact sciences, as compared to males. While this seems to simply confirm common wisdom, it is important to stress that these gender effects are found even after having controlled for gender differences in the high school education background. For example, females have a lower willingness to pay for exact sciences than arts of € 2,400 relative to males, even if they both have the same science high school background.

Aggregation (σ)

Finally, consider the aggregation parameter σ, which is interacted with the log of the number of variants K_j available at aggregate study option j. It measures the degree to which preferences are correlated across the K_j variants over which we aggregated. In the two aggregate models, $\sigma < \rho$, which is inconsistent with the restrictions of the nested logit model.[35] In the third, "disaggregate" model, $\sigma = 0.950 > \rho$, but it is still quite close to ρ. This means that preferences only show weak additional correlation over the variants available at each study option. This finding suggests the need for even more detailed disaggregate analysis, to study educational choices at even more disaggregate levels. We leave this as a topic for further research.

[35] T-statistics also showed that the difference is significant.

1.4.2 Cost elasticities

Many of our empirical findings can be summarized by the own- and cross-cost elasticities of demand. We focus on the semi-elasticities, defined as the percentage change in the number of students in response to an absolute increase in the monetary costs x_{ij} of a given study option or subset of study options. We consider here an absolute cost increase by € 1,000 (or equivalently, given our definition of x_{ij}, an increase in the daily commuting distance by 9km for a pupil traveling at a speed of 60km/h).[36]

The estimated cost elasticities provide information as to how participation and schooling would change in response to uniform or differentiated tuition fee increases. They may also give a first impression on the possible effects of a reduction of supply, which is essentially a very large cost increase for a subset of study options. Finally, the cost elasticities are informative in interpreting the results of a more complete welfare analysis of reform.

We compute the cost elasticities at three different levels: the level of the market, the program type (colleges versus universities), and the program fields.

Uniform cost increase

Table 1.6 considers the effects of a uniform cost increase by € 1,000 on colleges (first column), universities (second column), and overall participation (third column). The first panel compares the elasticities as implied by the aggregate logit, the aggregate nested logit and the disaggregate nested logit. The results differ dramatically. While the logit model would predict overall participation to drop by a substantial 13.79%, the aggregate nested logit model predicts a drop of only 1.62%, and the disaggregate nested logit model a drop of an even lower 0.91%. These large differences across models follow from our finding that pupils have quite strongly

[36] More formally, denote the predicted probability that individual i chooses study option j by $\widehat{P}_{ij}(x_i)$, where $x_i = (x_{i1} \cdots x_{iJ})$ is the $J \times 1$ vector of individual i's monetary costs for the various study options. Let δ be a $J \times 1$ vector of ones and zeros, where the ones denote the study options for which there is a cost increase by € 1000. The semi-elasticity of demand for all study options $j \in A$ with respect to a cost increase 1000δ is then defined as $\sum_i \sum_{j \in A} \left(\widehat{P}_{ij}(x_i) - \widehat{P}_{ij}(x_i + 1000\delta) \right) / \sum_i \sum_{j \in A} \widehat{P}_{ij}(x_i)$. For example, suppose that the set A consists of all study options and all elements in δ are equal to 1. The semi-elasticity then refers to the percentage change in the total number of students in response to a uniform cost increase by € 1000.

correlated preferences across study options, i.e. they perceive the various study options as close substitutes ($\rho = 0.95$). Hence, while mobility costs matter in their schooling decisions, they play only a limited role in their participation decisions. In all models the relative drop in students is larger at colleges than at universities, e.g. -1.09% versus -0.51% in the disaggregate nested logit model; the absolute drop at colleges is even higher since colleges have a larger market share.

The second panel shows how the elasticities differ among pupils. Males and foreigners are more likely to drop out than others. For example, male students would drop their overall participation by 1.07% compared to a drop of 0.78% for female students.[37] Students with no repetitions are less likely to drop out than students with one or two years of repetition (-0.65% versus -1.41% and -2.14%). The most important differences are found between students from different high school background: students with a general high school background would reduce participation by only 0.5%, whereas students from technical and professional high schools would drop participation by, respectively, 1.35% and 2.58%. In sum, the empirical results show that the overall demand for higher education is highly inelastic, although there are some clear differences between individuals.

Cost increases by program type: colleges versus universities

Additional insights are obtained by considering the cost elasticities at lower levels of aggregation. Table 1.7 presents the semi-elasticities at the level of the program type: vocational programs at colleges versus academic programs at universities. Cost increases by colleges only or by universities evidently have even smaller effects on total participation (last column). However, underlying these small total effects, there are large shifts in demand. A € 1,000 cost increase to all colleges reduces college demand by almost 13%, and a € 1,000 cost increase to all universities reduces university demand by an even larger 24%. These findings are consistent with our earlier discussion on the role of mobility costs. Since pupils have strongly correlated preferences across study options, they are quite willing to substitute be-

[37] The ratio of these changes is similar to the odds ratio, which is equal to $\exp(\gamma_0^l)$ for the l-th individual characteristic.

tween colleges and universities in response to a differentiated cost increase, even though they are unlikely to refrain from participation altogether.

We can use these results to assess the government's historic efforts to promote participation by investing in a large college network with a broad geographic coverage. Our estimated cost elasticities suggest that these efforts only have a negligible effect on total participation. The investment efforts thus mainly lead to a substitution from universities to colleges. In this sense, we may conclude that the government's policy has essentially not lead to more democratization, but rather to a diversion away from universities. This relates to Rouse's (1995) findings on the impact of U.S. community colleges on educational attainment. She also found that colleges did not increase the likelihood of attendance (though they may have led to an increase in the number of years of schooling). However, even if the promotion of colleges did not have an effect on democratization, this does not mean it is undesirable. The diversion to colleges may be efficient or inefficient depending on the benefits to pupils and the different costs of supplying education at colleges and universities. We will turn to that question in our welfare analysis below.

Cost increases by program field

Cost elasticities at the lower level of the program field provide interesting additional information. For example, they are relevant in assessing regulatory policies to promote certain study programs. They are also of interest in assessing the effects of introducing differentiated tuition fees. To our knowledge, there are no previous estimates of elasticities in higher education at the level of the program field.

Table 1.8 shows the estimated semi-elasticities for eight disciplines (arts, social sciences, biomedical sciences, and exact sciences; of either the vocational or the academic type). The own-cost elasticities on the diagonals show that pupils are quite cost-sensitive for all disciplines. The elasticities tend to be lower for the disciplines with the higher market share. For example, vocational biomedical sciences have by far the highest market share and also the lowest own-cost elasticity. However, market share is not the only relevant factor. For example, academic social sciences and vocational exact sciences have a similar market share, but pupils are much more cost sensitive for the former.

The cross-cost elasticities reveal several additional interesting patterns. It is best to read the cross-elasticities by row. Notice first that the cross-cost elasticities would be the same for all fields on the same row if all individuals were identical (no observed or unobserved heterogeneity). This follows from the IIA property of the logit model, saying that identical pupils shift proportionally to other alternatives. We earlier found however that pupil heterogeneity does matter in explaining educational choices. This is indeed reflected in the pattern of cross-cost elasticities, which vary widely within each row of the table. For example, the last row shows that a rise in the costs of academic exact sciences would generate much more substitution to other academic sciences than to vocational sciences; and among the vocational sciences the gains would mainly go to the vocational exact sciences.

This example illustrates a more general pattern for the cross-cost elasticities: pupils tend to mainly substitute within the academic or within the vocational program types, and to the extent that they substitute across types they would especially choose the "twin" program field of the other type. There is thus generally a dominance of the program type dimension over the program field dimension. In a few cases this dominance is somewhat weak: vocational exact sciences loose a comparatively high amount to academic sciences (fourth row), and academic arts loose relatively much to vocational arts (fifth row). In one case the dominance of the program type over the program field is actually reversed: vocational arts loose more to academic arts than to any other vocational program (first row). This is consistent with the high quality reputation of the vocational arts programs relative to academic arts (e.g. the language interpreter programs).

As a final remark, note that exact sciences and biomedical sciences are the closest neighbors, and so are social sciences and arts: in almost all cases, substitution mainly occurs to these neighbors. The only exception occurs on the second and third columns, where it appears that vocational biomedical and vocational social sciences are closest neighbors. This can be explained by the nature of many of these vocational programs (e.g. nursing).

Concluding remarks

The estimated elasticities show that uniform cost increases have little overall effects on the demand for higher education, though they can somewhat change the composition of demand. In contrast, cost increases by program type and program field lead to large shifts in the composition. One may use these findings to draw some tentative conclusions on policy reform. On the one hand, the low market-level elasticities suggest that a uniform tuition fee may generate large distributional effects, and comparatively lower total welfare improvements. On the other hand, the large elasticities at the level of the program type and program field, suggest that differentiated tuition fee increases may involve additional distributional and welfare effects. To obtain more insights, we turn to an illustrative welfare analysis next.

1.4.3 Implications for policy reform

To illustrate how our empirical results can be useful in assessing policy reform, we focus on the effects of raising tuition fees within a centralized public system, i.e. keeping other things such as the quality and the diversity of supply constant. Such an analysis is highly relevant since, as we have seen in section 2, fees are currently far from sufficient to cover even the variable cost per student, let alone the fixed costs. An analysis of more drastic reforms, such as decentralizing decision making to the institutions, is beyond the scope of this paper, since it would require a better empirical understanding on how the institutions of higher education compete.

Framework

We make the following assumptions.

- Pupils can borrow at a competitive interest rate to finance their educational expenses. This ensures that increases in tuition fees do not cause pupils to drop out because of capital constraints. Barr (2004) and others have discussed how this can be accomplished through appropriately designed income-contingent student loans.

- Pupils can deduct their educational expenses from their (future) taxable income. This ensures that a progressive income tax system does not distort the incentives to invest in higher education; see Bovenberg and Jacobs (2005) and Jacobs and van der Ploeg (2005).[38]

- The private (Mincer) returns to higher education are equal to the social returns, i.e. there are no spillovers to others from investing in higher education. Based on a discussion of the available micro and macro empirical evidence, Jacobs and van der Ploeg (2005) conclude that this is a realistic assumption. It allows us to directly use the estimates of our random utility discrete choice model to compute the changes in consumer surplus after a change in tuition fees.

- The government can regulate the colleges and universities, so that they do not change the quality or diversity of supply in response to an increase in tuition fees. Variable subsidies are granted on a cost basis. This allows us to treat the government and the higher education institutions as an integrated entity, and use the government's net revenues (tuition fee revenues minus the subsidy costs) as a measure of producer surplus.

- Progressive income taxes ensure the socially desirable income distribution. Atkinson and Stiglitz (1976) provide conditions under which this is the case. This allows us to abstract from equity considerations.

Based on these assumptions we can assess the welfare effects of tuition fee increases in terms of consumer and producer surplus. Write the indirect utility $V_{ij}^{*} = V_{ij} + (1-\sigma)\ln(K_j)$, where V_{ij} is given by (1.4), as a function of the $J \times 1$ tuition fee vector $t = (t_1 \cdots t_J)$, i.e. $V_{ij}^{*} = V_{ij}^{*}(t)$ for $j \neq 0$. The nested logit model gives the following expression for pupil i's expected surplus as a function of t (see

[38] The result that educational expenses should be tax deductable, or equivalently that the educational subsidy rate should be equal to the marginal income tax, closely relates to Diamond and Mirlees' (1971) result that the optimal tax rate on intermediate goods is zero.

e.g. McFadden (1981)):

$$CS_i(t) = \frac{1}{\alpha_i}\left(\sum_{j=1}^{J}\exp(V_{ij}^{*}(t)/(1-\rho))\right)^{(1-\rho)} + \exp\left(V_{i0}\right).$$

The average consumer surplus per pupil is $CS = \sum_{i=1}^{I} CS_i/I$, where I is the number of pupils. The variable part of producer surplus per pupil (or government's variable net revenue) for a specific study option j, as a function of t, is equal to

$$PS_j(t) = (t_j - c_j)\sum\nolimits_i P_{ij}(t),$$

where $P_{ij}(t)$ is the probability that individual i chooses program j as a function of t, and c_j is the constant variable cost per student of program j. Average producer surplus per pupil is $PS(t) = \sum_{j=1}^{J} PS_j(t)/I$.

Direct estimates of the variable cost per student c_j are not available. As an indirect measure we use the government's variable subsidy per student, since these are granted on a cost basis as discussed in section 2. Table 1.2 summarized how the variable subsidies, and hence the estimated variable costs, tend to be higher for the biomedical and exact sciences, especially at the universities. We will present the results from the estimated variable costs of the second panel of Table 1.2, but the results are very similar when the alternative estimates in the first panel were used.

The most simple welfare analysis would simply look at the sum of consumer and producer surplus. However, this would ignore that the social costs of public funds λ may be greater than zero, i.e. that the government may need to levy distortionary taxes elsewhere to finance a higher education deficit. Estimates of the social costs of public funds vary widely, from € 0.17 to over € 1.65 per Euro of public funds raised as discussed in Bird (2005). Diewert, Lawrence and Thompson (1998) suggest using a number of at least € 0.23. We take a conservative approach and compute total welfare as $CS(t) + (1+\lambda)PS(t)$, where λ is either equal to 0, or equal to Diewert et al.' s 0.23.

Findings

Table 1.9 shows the effects of both uniform and differentiated tuition fee increases. The first two columns show the size of the considered fee increases. The next four columns show the effects on per pupil consumer surplus, net revenues and total welfare assuming the cost of public funds λ is either zero or € 0.23. The final two columns show the associated effects on participation.

The first row shows the effects of a "small" uniform tuition fee increase of € 1,000. This is small in the sense that it is still insufficient to cover the variable costs per student (see Table 1.2). Consumer surplus drops by € 657 per pupil.[39] Producer surplus increases by an amount of € 670 per pupil. Hence, there are large distributional effects from students to the government (tax payers). The total welfare increase depends on how one values the increase in producer surplus: it increases by a small € 13 per pupil if the social costs of public funds are zero ($\lambda = 1$), but by a much higher amount of € 167 if $\lambda = 0.23$.

The second row compares the € 1,000 uniform increase with a differentiated fee increase that yields an equivalent increase in producer surplus: we take a fee increase of € 750 at colleges, which requires a fee increase of € 1,579 at universities to keep producer surplus constant. This differentiated fee increase implies that welfare increases by an additional € 12 per pupil relative to the uniform fee increase. This increase is due to a shift in demand from the universities to the colleges, which operate at a lower variable cost (Table 1.2). This shows that the earlier discussed diversion effects to colleges are not necessarily bad from a total welfare point of view. Nevertheless, it is also striking that differentiating fees between colleges and universities only improves total welfare by a small amount: we attribute this to the fact that the shift to the colleges does not only imply a lower variable cost of supply, but also a lower benefit to the pupils.

To gain further insights we subsequently consider the effects of more drastic cost-based fee increases, i.e. fee increases that are sufficient to exactly cover the variable part of producer surplus. The third row of Table 1.9 considers the effect of a uniform cost-based fee increase, which amounts to a required fee increase by € 2,810. Since the variable costs per student vary across program types and fields, such a fee increase implies some cross-subsidization from colleges to universities, and from arts and social sciences to biomedical sciences and exact sciences. By

[39] This is roughly proportional to the fraction of eligible pupils that choose to study, as expected from a discrete choice model.

construction, (variable) producer surplus becomes zero, an increase by € 1,852 per pupil relative to the status quo. There is therefore a large shift in distribution from students to producers (the government). Total welfare increases by the small amount of € 22 per pupil if $\lambda = 0$, and by the much larger amount of € 448 if $\lambda = 0.23$.

The fourth row shows how welfare further improves after a differentiated cost-based fee increase, i.e. such that the variable costs of each individual program are covered (implying no longer a cross-subsidization). If $\lambda = 0$, these tuition fees are also the first-best levels. Total welfare now increases by an additional € 100 relative to the uniform cost-based fee increase. This shows that fee differentiation has some modest effect on total welfare, but the effect should not be exaggerated.

The final row of Table 1.9 considers the welfare effects of adding a uniform markup over the cost-based levels. To illustrate, we consider a uniform markup of € 5,000, which is roughly sufficient to cover the fixed costs of higher education (in addition to the variable costs). If $\lambda = 0$, such a uniform markup lowers welfare relative to the first-best cost-based fees (by about € 80 per pupil), but it still raises welfare relative to the status quo (by the small amount of € 36 per pupil). In contrast, if $\lambda = 0.23$ total welfare per pupil further increases by € 1,150 relative to the status quo.[40] Note that we also considered the welfare effects from introducing non-uniform markups over marginal costs (i.e. Ramsey pricing), to exploit differences in the elasticities; we found that the additional gains are negligible, which is due to the fact that the estimated program field-level cost elasticities are quite large and similar to each other (see Table 1.8).

This discussion focused on the effect of tuition fee increases on total welfare. To gain additional intuition, the last two columns of Table 1.9 show how participation changes in response to the tuition fee increases. Consistent with our earlier discussed cost elasticities, overall participation generally does not drop by very much for the small fee increases (drop by less than 1%) but also not for the more

[40] We also computed the optimal uniform markup under $\lambda = 0.23$. This amount to a markup over costs of € 15,200. This very high number is due to the very low cost elasticity with respect to the overall participation decision.

drastic cost-based fee increases (drop of slightly more than 2%). Only if fees increase to have a € 5,000 markup, participation drops considerably (-7%). As a final point, the differentiated fee increases are accompanied by substantial student shifts from the universities to the colleges. This again emphasizes that a diversion of students from university to colleges is not necessarily harmful from a total welfare perspective, due to the associated variable cost savings.

Concluding remarks

We can summarize this discussion as follows. First, uniform cost-based tuition fee increases achieve most of the welfare gains; the additional gains from fee differentiation are relatively unimportant. The welfare increases are relatively large even under conservative assumptions on the social cost of public funds. If one ignores the social cost of public funds, the welfare gains are relatively small, but there is still a substantial redistribution from students to outsiders.

1.5 Conclusions

We have analyzed the determinants of participation and schooling in a public system of higher education, using a unique data set on pupils' study choices. One of our central findings is that pupils perceive the available institutions and programs as close substitutes, implying an ambiguous role for travel costs: they hardly affect the participation decisions, but have a strong impact on the schooling decisions. In addition, high school background plays an important role in both participation and schooling. Our empirical analysis generalizes previous work, which has focused on the participation rather than the schooling decision (where and what to study). Based on information of travel costs, we can indirectly infer the effects from raising costs including tuition fees at a high level of detail.

Our empirical results can contribute to informing the debate on reforming public systems of higher education. As an illustration, we have assessed the effects of tuition fee increases. Uniform cost-based tuition fee increases achieve most of the welfare gains. The additional gains from fee differentiation are relatively unimportant. The welfare gains are quite large if one makes conservative assumptions on the social cost of public funds, and there is a substantial redistribution from students to outsiders. Our empirical framework may be used to assess the effects of additional policy reforms of public systems. For example, in several countries governments aim to rationalize the supply by reducing the number of institutions through associations and/or reducing the number of duplicated programs. In future research, it would be of strong interest to evaluate the efficiency and distributional effects of these and other, more drastic reforms, such as decentralizing decision-making to the universities and colleges.

1.6 Tables & Figures

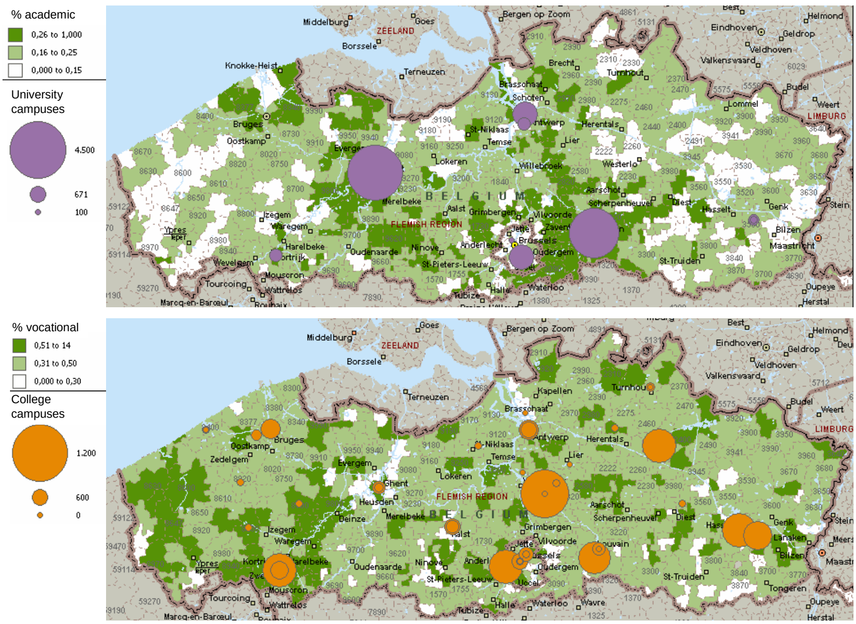

Figure 1.1: Participation in higher education, by postal code

Table 1.1: Supply of Higher Education in Flanders (2001)

	Colleges (vocational education)		Universities (academic education)	
	Non-catholic	Catholic	Non-catholic	Catholic
Number of campuses				
Total	16	28	5	4
offering degrees in				
Arts	5	7	2	4
Social Sciences	12	21	3	4
Biomedical Sciences	10	17	5	2
Exact Sciences	14	15	5	2
Number of students				
Total	9,899	15,283	6,658	5,641
enrolled for a degree in				
Arts	1,016	791	943	933
Social Sciences	5,538	9,952	2,996	3,116
Biomedical Sciences	839	1,709	1,312	798
Exact Sciences	2,506	2,831	1,407	794

Note: Own calculations based on our dataset from the Flemish Ministry of Education.

Table 1.2: Variable subsidies per student in Euros

	Colleges	Universities
2001 subsidy scheme		
Total	2,973	3,891
Arts	2,456	2,593
Social Sciences	2,772	2,601
Biomedical Sciences	3,671	5,186
Exact Sciences	2,994	5,186
2005 subsidy scheme		
Total	3,113	3,937
Arts	2,456	2,652
Social Sciences	2,865	2,807
Biomedical Sciences	3,683	5,000
Exact Sciences	3,448	5,290

Note: The top panel is based on the variable subsidy scheme for higher education in vigor until 2001 (Universiteitendecreet, 1991; Hogescholendecreet, 1994). The bottom panel is based on the proposed new subsidy scheme (Vandenbroucke, 2005). We report student-weighted averages of subsidies per study field for both colleges and universities.

Table 1.3: Summary statistics of 2001 eligible pupils

	All Pupils	Students	Outsiders	College	University	Non-catholic	Catholic
Demographic							
male	0.48	0.45	0.56	0.45	0.45	0.47	0.43
foreign	0.02	0.01	0.04	0.01	0.01	0.02	0.01
catholic high school	0.75	0.78	0.70	0.79	0.76	0.67	0.87
Ability							
years of repetition	0.61	0.36	1.11	0.46	0.16	0.40	0.34
	(1.06)	(0.95)	(1.09)	(0.99)	(0.83)	(1.05)	(0.87)
general high school	0.48	0.60	0.21	0.44	0.94	0.63	0.58
classical languages	0.11	0.14	0.04	0.05	0.33	0.15	0.13
modern languages	0.19	0.24	0.09	0.22	0.27	0.23	0.24
economics	0.15	0.19	0.07	0.19	0.17	0.17	0.20
sciences	0.16	0.20	0.07	0.11	0.40	0.24	0.18
mathematics	0.23	0.30	0.09	0.15	0.60	0.34	0.27
technical high school	0.35	0.33	0.39	0.47	0.04	0.29	0.35
´product'-focused	0.14	0.12	0.19	0.17	0.02	0.11	0.12
Mobility							
Distance (kms) by road to campus	n/a	34.71	n/a	30.96	42.38	35.73	33.90
	n/a	(28.17)	n/a	(25.65)	(31.37)	(28.19)	(28.13)
Time (mins) by road to campus	n/a	30.74	n/a	28.33	35.67	32.13	29.64
	n/a	(17.33)	n/a	(16.2)	(18.47)	(17.59)	(17.03)
Travel cost to campus (x10,000€)	n/a	0.38	n/a	0.35	0.46	0.40	0.37
	n/a	(0.28)	n/a	(0.25)	(0.31)	(0.28)	(0.28)
Time (mins) by train to campus	n/a	47.60	n/a	44.33	54.30	47.62	47.59
	n/a	(28.04)	n/a	(26.19)	(30.41)	(27.83)	(28.20)
Number of observations	55,905	37,481	18,424	25,182	12,299	16,557	20,924

Note: Standard errors for the continuous variables are in parentheses. Demographic and ability data are based on our data set from the Flemish Ministry of Education; mobility statistics are based on own calculations using postal code information.

Table 1.4: Participation and schooling decisions - Comparison of alternative models

Parameter	Aggregate logit model Estimate	t	Aggregate nested logit model Estimate	t	Disaggregate nested logit model Estimate	t
Outside option (γ_0)						
intercept	4.10*	(26.52)	1.51*	(12.39)	1.18*	(14.60)
male	0.22*	(3.85)	0.27*	(5.61)	0.31*	(7.55)
foreign	1.17*	(6.23)	1.00*	(6.15)	0.77*	(6.59)
catholic high school	0.20*	(3.28)	-0.33*	(-6.20)	-0.35*	(-7.90)
years of repetition	0.47*	(13.04)	0.45*	(15.57)	0.47*	(20.61)
general high school[1]	-1.81*	(-13.70)	-2.19*	(-20.44)	-2.14*	(-21.00)
classical languages	0.82*	(6.21)	-0.34*	(-3.01)	-0.14	(-1.55)
modern languages	0.03	(0.24)	0.10	(1.02)	0.05	(0.63)
economics	-0.36*	(-2.94)	-0.17	(-1.62)	0.08	(0.89)
sciences	0.29	(2.46)	-0.07	(-0.67)	0.02	(0.17)
mathematics	0.34*	(3.08)	-0.08	(-0.80)	0.00	(-0.05)
technical high school[1]	-1.73*	(-17.41)	-1.38*	(-18.55)	-1.19*	(-16.88)
´product'-focused	0.57*	(6.37)	0.21*	(2.94)	0.24*	(3.85)
Travel cost (α_i)						
intercept	5.44*	(18.14)	6.34*	(19.44)	6.46*	(17.84)
φ	-0.41*	(-2.20)	-0.42*	(-2.09)	-0.49*	(-2.12)
male	-0.10	(-0.86)	-0.06	(-0.53)	0.24	(1.83)
foreign	-0.63	(-1.24)	-0.22	(-0.38)	0.63	(1.30)
catholic high school	-0.30*	(-2.13)	-0.62*	(-3.96)	-0.45*	(-2.68)
years of repetition	-0.01	(-0.18)	0.04	(0.49)	0.07	(0.74)
general high school[1]	0.28	(1.02)	0.06	(0.21)	-0.36	(-1.09)
classical languages	-0.58*	(-2.93)	-0.75*	(-3.59)	-0.53*	(-2.36)
modern languages	-0.01	(-0.07)	0.07	(0.33)	0.42	(1.89)
economics	0.29	(1.38)	0.25	(1.11)	0.50*	(2.06)
sciences	-0.57*	(-2.89)	-0.62*	(-2.96)	0.01	(0.06)
mathematics	-0.20	(-1.06)	-0.17	(-0.84)	-0.17	(-0.77)
technical high school[1]	1.42*	(6.13)	1.67*	(6.58)	1.41*	(4.80)
´product'-focused	-1.05*	(-5.50)	-1.30*	(-6.32)	-1.41*	(-6.33)
Nesting parameters						
ρ	0 (not estimated)		0.898*	(33.90)	0.946*	(42.80)
σ	-0.048*	(2.01)	0.888*	(30.42)	0.950*	(46.60)
Slope parameters ($\gamma_j, j \neq 0$)						
Catholic Institution[2]	*included*		*included*		*included, see table 1.5*	
Academic program[3]	*included*		*included*		*included, see table 1.5*	
Vocational long program[3]	*not included*		*not included*		*included, see table 1.5*	
Study field characteristics[4]	*not included*		*not included*		*included, see table 1.5*	
Fixed effects (β_j)	*included*		*included*		*included, see table 1.5*	
Observations	778,464		778,464		2,981,735	
individuals	*14,416*		*14,416*		*19,237*	
alternatives	*54*		*54*		*155*	
Mean log likelihood	-0.0383068		-0.037747		-0.0032785	

Notes: t-statistics in parentheses. * statistical significance at 5% level

[1] base category = professional/arts high school

[2] base category = non-catholic study option

[3] base category = vocational study option (aggregate models), vocational short study option (disaggregate model)

[4] base category = arts study option

Table 1.5: Schooling decisions - Results from disaggregate nested logit model

	Religious orientation[1]	Type of Higher Education[2]		Study Field[3]		
Parameter ($\gamma_j, j \neq 0$)	Catholic	Vocational long	Academic	Social	Biomedical	Exact
intercept	-0.74*	-0.52*	-2.99*	-1.70*	-3.12*	-2.33*
	(-4.48)	(-2.12)	(-9.88)	(-6.13)	(-8.55)	(-8.59)
male	-0.03	0.52*	0.23*	0.31*	-0.62*	1.43*
	(-0.49)	(6.38)	(3.12)	(3.29)	(-5.41)	(13.85)
foreign	-0.16	0.50	1.07*	0.03	0.08	-0.40
	(-0.67)	(1.41)	(3.44)	(0.08)	(0.17)	(-0.95)
catholic high school	1.05*	0.19	0.15	0.08	0.20	0.33*
	(15.27)	(1.79)	(1.49)	(0.64)	(1.36)	(2.53)
years of repetition	-0.10*	-0.28*	-0.22*	-0.02	-0.14	-0.14
	(-2.50)	(-4.30)	(-3.68)	(-0.25)	(-1.56)	(-1.79)
general high school[4]	0.10	0.23	2.71*	2.40*	2.65*	0.71*
	(0.78)	(0.96)	(10.16)	(9.64)	(7.86)	(2.67)
classical languages	0.08	0.92*	1.88*	-0.52*	-0.48*	-0.81*
	(0.88)	(5.82)	(14.83)	(-3.83)	(-2.92)	(-5.12)
modern languages	-0.08	0.41*	-0.03	-0.53*	-0.73**	-0.65*
	(-0.94)	(3.03)	(-0.32)	(-4.08)	(-4.43)	(-4.07)
economics	0.11	0.84*	0.11	1.35*	0.67*	0.43*
	(1.19)	(5.85)	(0.96)	(8.90)	(3.48)	(2.36)
sciences	-0.06	0.89*	1.01*	0.57*	1.73*	1.39*
	(-0.67)	(6.34)	(8.80)	(3.98)	(10.37)	(8.87)
mathematics	-0.19*	1.60*	1.37*	0.91*	1.22*	1.98*
	(-2.13)	(12.09)	(12.81)	(7.02)	(7.53)	(12.61)
technical high school[4]	-0.14	-0.42	0.32	2.86*	3.45*	1.12*
	(-1.23)	(-1.87)	(1.17)	(10.84)	(10.13)	(4.26)
'product'-focused	-0.11	0.81*	-0.17	-0.09	1.31*	2.94*
	(-1.19)	(5.26)	(-0.91)	(-0.34)	(4.66)	(10.77)

Notes: t-statistics in parentheses. * statistical significance at 5% level
[1] base category = non-catholic study option
[2] base category = vocational short study option
[3] base category = arts study option
[4] base category = professional/arts high school

Table 1.6: Cost elasticities at market level

	Effect on[1]: Colleges	Universities	Overall
All pupils			
Logit	-16.43	-0.91	-13.79
	(0.29)	(0.24)	(0.25)
Aggregate nested	-1.95	-0.87	-1.62
	(0.51)	(0.23)	(0.43)
Disaggregate nested	-1.09	-0.51	-0.91
	(0.45)	(0.21)	(0.38)
Pupils by profile (disaggregated nested logit model only)			
male	-1.28	-0.60	-1.07
female	-0.94	-0.44	-0.78
Belgian	-1.08	-0.50	-0.90
foreign	-2.11	-1.24	-1.80
no repetition	-0.78	-0.44	-0.65
1 year repetition	-1.51	-0.91	-1.41
2 years repetition	-2.20	-1.54	-2.14
catholic high school	-1.00	-0.47	-0.83
non-catholic high school	-1.49	-0.74	-1.29
general high school	-0.54	-0.46	-0.50
technical high school	-1.36	-1.33	-1.35
professional/arts high school	-2.58	-2.54	-2.58
Current market share	45.05	22.00	67.04

Notes: Standard errors in parentheses.
[1] Reported as semi-elasticities: % change in market share given a uniform cost increase of € 1,000.

Table 1.7: Cost elasticities at program type level

	Effect on[1]: Colleges	Universities	Overall
Increase for colleges	-12.88	26.30	-0.72
	(0.44)	(0.54)	(0.30)
Increase for universities	10.61	-24.03	-0.13
	(0.21)	(0.40)	(0.06)
Current market share	45.53	20.47	66.00

Notes: Standard errors in parentheses.
[1] Reported as semi-elasticities: % change in market share given a cost increase of € 1,000.

Table 1.8: Cost elasticities at program field level

	Effect on[1]: Vocational study fields				Academic study fields			
	Arts	Social	Biomedical	Exact	Arts	Social	Biomedical	Exact
Increase for:								
Vocational * Arts	-43.03	2.87	1.99	2.08	4.09	2.48	1.74	1.43
Vocational * Social Science	28.34	-26.60	37.89	18.69	15.84	17.86	10.55	8.57
Vocational * Biomedical Science	2.36	4.15	-45.53	3.31	1.87	2.07	2.87	1.89
Vocational * Exact Science	5.40	5.43	8.03	-33.46	2.00	3.09	3.29	7.41
Academic * Arts	3.79	1.55	1.43	0.72	-39.17	4.26	3.29	2.19
Academic * Social Science	5.90	4.38	4.09	2.92	10.91	-38.28	10.76	9.78
Academic * Biomedical Science	1.72	1.13	2.42	1.29	3.52	4.51	-38.49	5.25
Academic * Exact Science	2.08	1.41	2.33	4.10	3.50	6.12	7.80	-36.44
Current market share	3.73	28.33	4.46	9.02	3.35	8.35	3.61	5.17

[1] Reported as semi-elasticities: % change in market share given a cost increase of € 1,000.

Table 1.9: Welfare effects of tuition fee increases

	Fee increase		Welfare effects[1]				Participation effects[2]		
	colleges	universities	consumer surplus	producer surplus	welfare (λ=0)	welfare (λ=0.23)	colleges	universities	total
Uniform small increase	+ €1,000	+ €1,000	-657.0	670.1	13.1	167.2	-1.09	-0.51	-0.91
Differentiated small increase	+ €750	+ €1,579	-645.1	670.1	25.0	179.2	8.04	-20.46	-0.80
Uniform cost-based increase	+ €2,810	+ €2,810	-1,830.8	1,852.3	21.6	447.6	-3.08	-1.46	-2.58
Differentiated increase to variable cost	$t_j = c_j$	$t_j = c_j$	-1,736.8	1,851.8	115.1	541.0	3.32	-14.98	-2.35
Uniform big increase	c_j + €5,000	c_j + €5,000	-4,881.7	4,918.2	36.5	1,167.7	-2.49	-17.31	-7.09

[1] The changes are in €/pupil and relative to the status quo.
[2] Reported as semi-elasticities: % change in market share given a cost increase of € 1,000.

1.A Appendix: The Data

We combine two main data sets: "pupils" and "students". Both are made available by the Flemish Ministry of Education. In addition to these data sets, we constructed a number of auxiliary data sets, describing additional choice and/or demographic characteristics.

- Pupils

  The pupils data set contains information on all 55,905 pupils who attended the last year of secondary school in the year 2001. For each pupil there is information on five variables, defining the pupil's *profile*: secondary school institution, study program during last year of secondary school, postal code, age (birth year), sex and nationality.

- Students

  The students data set contains information on all students who first registered for a higher education program in either 2001 or in 2002. Information is available on each student's profile, according to the same five variables as in the pupils data set. In addition, the data set contains each student's choice of higher education institution, campus and study program. Finally, there is information on the year of graduation from secondary school. We use this last variable to extract the subset of students who graduated from a secondary school in the year 2001. This amounts to a total number of 35,562 first registering students, out of which the large majority (34,395 students) immediately registered after secondary school graduation in 2001, and a small group registered with one year of delay in 2002 (1,167 students). Hence, it is reasonable to assume that the fraction of 2001 pupils that first registers to a higher education institution after 2002 is negligible.

Our task is to distinguish between pupils who become students and pupils who remain "outsiders", i.e. who do not register at a higher education institution in 2001 or 2002. In principle, this can be done by combining the pupils and the students data sets, based on their profiles as defined by the five common variables:

a pupil for which there is a successful match with a student can be identified as a student, while a pupil for which there is no successful match with a student can be identified as an outsider. In practice, we also found a small number of students for which there is no successful match with a pupil. Based on correspondence with the ministry of education, we attribute this to some inconsistencies in the definition of the pupils' profiles rather than in the definition of the students' profiles. We therefore adopt the following approach when matching the pupils and students data sets. We identify as students all individuals in the students data set (even if no successful match with a pupil was found). We then identify as outsiders all pupils for which there is no successful match with a student. This will generate a data set with slightly too many individuals that are identified as outsiders: this excess number is equal to the number of students for which no successful match with a pupil was found. We then randomly drop this excess number of individuals from the outsiders. Our combined data set then contains information on 55,905 pupils: 35,562 students and 20,343 outsiders.

In addition to the two main data sets, we constructed a number of auxiliary data sets. First, we have information on various characteristics of the secondary school institution and the study program during the last year of high school. The information on the secondary school institution includes the postal code of the secondary school and the network affiliation (free subsidized, official subsidized, or community). The information on the study program during the last year of secondary school includes the main category (i.e. general, technical, arts or professional high school program), as well as more specific information (focus on languages, math, science, etc.). Second, we have information on the analogue characteristics of the higher education institution and study program. Third, we have information on the distribution of several demographic variables: average income by postal code, and average commuting distance and commuting time of the active labor force by postal code. Fourth, we make use of Microsoft's route planning software to compute the distance and car travel time between each individual's postal code address and each higher education institution's postal code address. The distance and travel time between an individual's postal code and the no-study alternative is set equal to the average distance travelled to work, by postal code. Finally, we use information provided by the Belgian railroad company to compute train travel times, i.e. train travel time between each individual's closest train station and each higher education institution's closest train station, plus car travel time to and from the respective stations.

Chapter 2: Reducing Supply Diversity in Higher Education

Abstract

Publicly financed systems of higher education have recently attempted to reduce the diversity of supply in various ways. We[41] study the profit and welfare effects of reducing supply diversity, against the background of a funding system reform in Flanders (Belgium). We find that the social desirability of cutting programs at institutions is limited to less than 10% of the cases, due to the students' low willingness to travel and relatively limited variable and fixed cost savings. Furthermore, the originally proposed version of the new funding system would often miss its purpose. In general, it gives an incentive to cut the smaller programs. However, we find that for the programs where cuts are undesirable, the system nevertheless encourages to cut 30-60% of the cases. Furthermore, for the minority of cases where program cuts are actually desirable, we find it provides the wrong incentive for up to half of the cases. These findings emphasize the complexities in regulating the diversity of supply in higher education, and serve as a word of caution towards the various other measures to cut supply diversity that have recently been introduced.

2.1 Introduction

The publicly financed systems of higher education in Europe have recently come under increased scrutiny to increase their economic efficiency (Nadeau & McNicoll, 2006; European Commission, 2006). While most European governments (except the U.K.) still show a reluctance to raise private contributions through tuition fees, several measures have been introduced to promote reductions in the variety of supply. Universities and colleges have been encouraged to form associations, and

[41] This chapter is joint work with Frank Verboven.

new public funding systems have been designed to encourage institutions to eliminate some of their study programs. There appears to be a common belief that such measures can save on (duplicated) fixed costs, without generating too much losses to consumers (students) from the reduced supply diversity.

This paper considers the effects of reducing supply diversity, against the background of a recent funding system reform in Flanders (Belgium). According to the original proposal in 2005, institutions would receive public funding based on their achieved concentration index, i.e. the average number of students per study program[42] (Vandenbroucke, 2005). It therefore provides incentives to eliminate the smaller programs. We address two main questions. First, does reducing supply diversity make sense from a welfare perspective? Second, does the concentration index provide the proper incentives to cut supply diversity, i.e. if and only if it is socially desirable?

To address these questions we estimate a model of (undergraduate) educational choice, accounting for the determinants of the students' decisions where and what to study. The welfare effects from cutting programs at institutions consist of consumer surplus losses, variable cost savings (or losses) due to an output reallocation effect, and fixed cost savings. The profit effects consist of tuition fee revenue losses, fixed cost savings, and the incentive provided by the concentration index funding system.

Our first main finding is that the social desirability of cutting programs at institutions is limited to less than 10% of the cases. This follows from the students' low willingness to travel to other institutions. Reducing supply diversity therefore results in consumer surplus losses that typically outweigh any possible variable or fixed cost savings. Our second main finding is that a funding system that would make use of a concentration index often misses its purpose. It creates incentives to cut programs in about half of the cases where this would be socially undesirable. Furthermore, for the minority of cases where program cuts are actually desirable,

[42] A more elaborate discussion of the final version of the new funding system, which does no longer include the originally proposed concentration index, is deferred to section 2.2.2.

the system does often not provide the proper incentives to do so.[43] Our findings emphasize the complexities in regulating the diversity of supply in publicly financed systems of higher education, and serve as a word of caution towards the various other measures that have recently been proposed. Policy makers often appear to be too pre-occupied with the fixed cost savings following program cuts: these may be too limited compared with the implied consumer surplus losses.

Our paper relates to the empirical industrial organization literature on product diversity. Several studies have estimated demand models to measure the effects of product introductions or eliminations. They typically focus on consumer surplus or gross producer surplus effects, excluding the difficult to observe fixed costs.[44] A few studies have accounted for the role of fixed costs, by adding an entry model to the demand side. In particular, Berry and Waldfogel (1999) infer fixed costs from a model of free entry, where entry occurs if and only if this is profitable.[45] This approach is not possible in our application, since the decision to supply study programs is subject to an untransparant government approval process. We therefore make the weaker assumption that institutions offer programs if (but not only if) this is profitable. This provides simple bounds on the fixed costs per program, and actually brings us quite far in drawing unambiguous conclusions about the total welfare effects and profit incentives of the concentration index funding system. Similar approaches may therefore be useful in other applications where there is no simple free entry process.

In the education economics literature there has been a long-standing concern with the efficienct use of of resources.[46] Several empirical papers identified the

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43 As we will see, programs cuts are mainly desirable for programs with a high variable cost per student, since this involves an output reallocation effect towards programs with lower variable costs. However, the funding scheme does not guarantee stronger incentives to cut these programs.

44 Petrin (2002), Hausman and Leonard (2002) and Nevo (2003) look at the consumer effects of new product introduction. Perloff and Ward (2003) also look at product eliminations and consider both consumer surplus and gross profits, using assumptions about pricing behavior.

45 For the large theoretical literature on free entry and optimal product diversity, see for example Spence (1976), Dixit and Stiglitz (1977), and Mankiw and Whinston (1986).

46 For example, Bergstrom et al. (1988) devised an empirical test to determine whether governments spend too much on public education.

importance of economies of scale in the provision of education,[47] thereby providing arguments in favour of reducing supply variety. However, the demand side of (higher) education remains underexplored. A notable exception is Long (2004). She conducts a thorough long-term analysis for the U.S. on the determinants of higher educational choice, including the role of distance and college characteristics. She does not, however, use these results to draw implications about reducing supply variety (an issue that may be of stronger relevance in the more regulated European systems).

The remainder of this paper is organized as follows. Section 2.2 discusses the relevant aspects of the higher education system in Flanders (Belgium), in particular the current supply diversity and the proposed funding scheme reform. Section 2.3 outlines the economic framework to analyze supply diversity. Section 2.4 presents the empirical model of educational choice and the empirical estimates. Section 2.5 uses the framework and empirical results to assess the profit and welfare effects. Finally, section 2.6 concludes.

2.2 Higher education in the region of Flanders

Our analysis is based on the case of Flanders (Belgium), and is representative for several other European countries. We focus our discussion on the current supply diversity and on the recent government policies aimed at reducing this diversity. For a more detailed background discussion of the supply and demand of higher education in Flanders, we refer to Kelchtermans and Verboven (2006) and Van Heffen and Lub's (2003) country report.

2.2.1 Institutions and study programs

There are two types of institutions offering higher education: colleges and universities. Colleges largely focus on teaching and offer vocational (or professional) study

[47] Riew (1966) and Cohn et al. (1989) found evidence of scale economies at the secondary school and higher education level, respectively. These findings suggest that education institutions could reduce their unit costs of operation by growing relative to their current size.

programs. Many of the colleges exclusively offer one-cycle (bachelor) study programs, but some offer two-cycle (bachelor + master) programs. Universities are active in both research and teaching and offer academic programs. These are typically two-cycle (bachelor + master) programs. In recent years, there has been a trend towards convergence between colleges and universities, especially regarding the two-cycle programs.[48] Several institutions have multiple campuses across the region.

There are ten main study fields: architecture, engineering, sciences, economics & business, education sciences, other social sciences (including law, political sciences, sociology, psychology, and their vocational counterparts), medicine & paramedics, bio-engineering, languages and cultural studies. These fields apply to both colleges and universities, except for sciences which are only offered at universities. Each field may consist of more than one "elemental" study program. For example, hotel management and marketing are study programs in the vocational economics & business field, while dentistry and medical sciences are programs in the academic medicine/paramedics field.

Table 2.1 provides an overview of the diversity of supply in the year 2001-2002. For each of the ten study fields, the table shows the number of campuses, the number of study programs, the number of incoming students (freshmen), and the average number of students per study program. The upper panel shows this information for colleges, and the lower panel for universities. There are 44 college campuses and 9 university campuses, which amounts to the high density of one campus per 250 km^2 throughout the region of Flanders. The total number of incoming students is larger at colleges than at universities (25,182 versus 12,299), but the average scale is lower (61 incoming students per study program for colleges versus 83 for universities). All fields are broadly available at many campuses throughout the region. This "duplication" of supply is especially large for vocational study

[48] This trend has been stimulated by the government. Already in 1991, a Decree stipulated the same rules for two-cycle vocational programs at colleges as for academic programs at universities. Colleges offering these two-cycle programs also became entitled to do applied research by means of co-operation agreements with universities. More recently, the Bologna Declaration and the subsequent Bachelor–Master reforms have strengthened these developments.

fields at colleges, in particular for engineering, economics & business, education sciences and medicine & paramedics, which are all available at more than 20 different college campuses. The average scale per study program is relatively low, notably for cultural studies at colleges or for science programs at universities (on average 19 and 35 incoming students per program, respectively).

In sum, Table 2.1 illustrates the high diversity of the supply of higher education in Flanders. There is a broad geographical coverage and a correspondingly small average scale, especially for the college campuses. Geographical coverage remains broad when considering the separate study fields. These observations will be useful when interpreting and evaluating the effects of the government policy towards the diversity of supply.

2.2.2 Government intervention

As in most European countries the Flemish undergraduate higher education system is entirely public. In this section we discuss the role of the government in the provision of subsidies, the regulation of tuition fees, and the control of the diversity and quality of supply.

The main role of the government consists in giving subsidies to institutions. Since it profoundly alters the way these subsidies are allocated to institutions, we give an overview of the evolution of the proposed new funding scheme for Flemish higher education since its conception in 2004 to the current "final draft" stage (July 2007). Our analysis in later sections will focus on the effects of one the incentives for reducing supply diversity that was proposed during the development of the new funding system.

The newly elected Flemish government taking office in 2004 announced the development of a new funding scheme for higher education. An important trigger for this initiative was the government's opinion that the number of institutions and study programs offered in higher education was too high and that a new funding scheme should contain explicit incentives to reduce supply diversity. More generally, it was argued that the new system should have the following properties:

transparency, predictability, fairness, efficiency and encouraging diversity and flexibility. The new system is to accomplish a series of objectives, such as increased participation, higher attainment, equal opportunities and a "more effective and rational supply" (Vlaamse Regering, 2007).

The first proposal for a new funding scheme was released for discussion with the higher education sector at the end of 2005. This proposal contained a number of financial incentives aiming to reduce the number of institutions and study programs. We focus on these incentives, ignoring those targeting, for example, higher attainment. First, institutions were required to reach a minimum size to be eligible for funding. Furthermore, phase out funding was provided for programs that an institution decided to cut and institutions could earn additional funding by jointly offering study programs. For very small programs an institution could obtain guaranteed minimum funding, provided it was the only institution in Flanders offering the program. A final incentive in the first proposal was the concentration index, defined as the institution's average program size, i.e. the average number of students per program. The higher this concentration index, the higher the subsidy of an institution would be. This incentive was put forward by the government as a key instrument to counter the fragmentation in Flemish higher education.

During the consultation process with the higher education sector, the funding scheme as originally proposed by the government was scrutinized and refined, resulting in the final proposal of 19 July 2007.[49] With respect to incentives for reducing supply diversity, the core of the original proposal remains intact. The final proposal retains the "minimum size" requirement and the bonus for eliminated study programs.[50] It additionally specified that this bonus may be increased if the institution draws up a reorganization plan that provides for a "sensible reorientation" of material assets and personnel. After consultation of the institutions, the concentration index incentive did not make it into the final proposal since it was considered too crude a measure. For example, it was argued by universities that it

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49 The final decree will undergo at most minor changes compared to the final proposal, if any, before becoming law. The new funding scheme for higher education in Flanders will enter in vigor on 1 January 2008.

50 A similar bonus is given in the case of mergers of study programs.

is common to pool students and “share” them across study programs so that critical mass is achieved whilst the concentration index is not able to capture such initiatives. Overall, the impact of the concentration index was considered difficult to evaluate and therefore the institutions suggested dropping the measure as part of the funding scheme. So despite the fact that the government in the final proposal reaffirms its position that “current higher education supply is too fragmented”, the key incentive for reducing supply diversity has been dropped after consulting the institutions. As an alternative, the Decree leaves the initiative to the higher education sector and requires all institutions active in a certain study field to come up with a joint “rationalization plan” by 1 January 2009. This plan must specify how many study programs the institutions wish to keep, the process and timing for carrying out the plan and how the study programs will connect to available research capacity. The proposed plans will be subjected to a panel of international experts and require approval by the Flemish government. The criteria that must be used for judging the rationalisation plans are listed in the proposal of the Decree (Vlaamse Regering, 2007b, art. 51). These criteria relate to the quality of programs, economies of scale and the available teaching and research capacity in terms of personnel and infrastructure. Absent from these criteria is the demand side i.e. the impact of reduced supply diversity on students or general welfare.

This paper does provide that perspective and determines the impact of reductions in supply diversity on overall welfare. Furthermore, it is interesting to evaluate the effects of a funding scheme using a concentration index incentive as a means to reduce supply diversity. In particular, it is illuminating to see how students’ substitution behavior resulting from a program cut affects the average program size at the institution and hence how a funding system incorporating such an incentive would influence institutions’ decisions. After all, institutions opposed against the use of the concentration index in the funding scheme pointing to measurement issues, but without a clear understanding of the role of the demand side. Therefore, in the remainder of the text we analyze a funding scheme that incorporates a concentration index as the main incentive to reduce supply diversity. We will refer to it as the “CI funding system”. It contains two main changes in the way it assigns subsidies to institutions compared to the former funding system (before 2004). In the old system, subsidies consisted of both a fixed and a variable component. The variable component represented a constant subsidy per student, varying across study programs on cost-based principles. The fixed component was independent of the number of enrolling students and varied between institutions on historical grounds.

In the CI funding system the constant subsidy per student has been made conform to the recent and more accurate estimates of the variable cost per student, obtained by Deen et al. (2005). Table 2.2 shows the current subsidy per student for the ten study fields (i.e. averaged across the study programs within each field). The subsidies tend to be lower for vocational programs at colleges than for academic programs at universities. They also show a wide variation across fields: the lowest levels are for humanities and social sciences and the highest levels for medical and exact sciences. These differences in subsidies per student clearly reflect the differences in the (estimated) variable costs per student.

Second, the CI funding system replaces the fixed subsidy by another variable subsidy, intended to promote institutions to reduce supply diversity. Each institution k receives a subsidy r per unit of its achieved concentration index C_k. As mentioned earlier, this index is essentially the average number of students per study program offered by institution k, i.e.:

$$C_k = \frac{Q_k}{J_k},$$

where Q_k is the total number of students and J_k is the total number of study programs at institution k.[51] In the next section we will show how this new variable subsidy may provide incentives to the institutions to reduce their supply diversity, as well as under which conditions this is desirable from a welfare perspective.

In addition to the subsidies, the government regulates the tuition fees. While the institutions have some discretion, in practice the tuition fees are very low and

[51] In practice, the index is slighlty more complicated (Vandenbroucke, 2005). It is normalized by the average index over all institutions. This normalized concentration index has to stay within bounds of 0.5 and 1.5. We account for this in our empirical analysis, but not in our discussion since it complicates the exposition and it only matters for a minority of the institutions. The lower bound is obtained for 5 and the upper bound for 4 out of the 53 institutions.

The subsidy r per 0.01 units of the (normalized) concentration index is € 16,000.

hardly show any variation. During the year of our study, the tuition fees were essentially uniform at € 425 for colleges and € 445 for universities. These low and uniform tuition fees are in sharp contrast with the high and widely varying subsidies or variable costs per student, shown earlier in Table 2.2.

Finally, the government excercises some direct control over the diversity and the quality of supply. The diversity is regulated since institutions are not automatically eligible to offer all possible study programs. In practice, the institutions form a continuous pressure to be entitled to supply additional subsidized programs. The CI funding system based on the concentration index may therefore be seen as an attempt to reduce this pressure. The quality of supply is controlled through a system of self-assessments and external visiting committees. While the government may in principle withdraw the authorization to offer a subsidized program if quality is insufficient, this rarely happens in practice.

2.3 Economic framework

We now provide an economic framework for analyzing both the demand, profit and welfare effects of reducing the supply diversity in higher education. This framework will serve as the basis for our empirical analysis in the next sections.

2.3.1 Demand, profits and welfare

There are K institutions. Each institution $k = 1 \cdots K$ offers J_k study programs, $j = 1 \cdots J_k$, so the total number of study alternatives is $J = \sum_{k=1}^{K} J_k$. There are I students, $i = 1 \cdots I$. Their demands are specified in section 2.4.1 and follow a discrete choice model: all students choose exactly one of the study alternatives and there is no outside good. The demand or number of students for program j at institution k is $q_{jk}(\mathbf{p})$, where $\mathbf{p}$ denotes the $J \times 1$ price vector $\mathbf{p}$ of all study alternatives (programs and institutions). The total demand or the number of students for institution k is the sum of the demands for all programs at institution k, i.e. $Q_k(\mathbf{p}) = \sum_{j=1}^{J_k} q_{jk}(\mathbf{p})$. Since all students choose exactly one of the study alternatives, total demand is equal to the total number of students $\sum_{k=1}^{K}\sum_{j=1}^{J_k} q_{jk}(\mathbf{p}) = I$ and hence is perfectly inelastic.[52]

The program-related profits of institution k consist of tuition fee revenues plus subsidies minus variable and fixed costs over all programs it offers.[53] Each program j has a constant variable cost per student c_j (common across institutions k) and a fixed cost F_{jk}. The subsidies consist of two parts. First, there is a constant and program-specific variable subsidy per student s_j. As discussed in the previous section this variable subsidy is cost-based, so that $s_j = c_j$. Second, there is an additional subsidy at the level of the institution k. As discussed in section 2, this used to be a fixed amount independent of the number of students. In the CI funding system, this fixed amount has been replaced by a variable subsidy r per unit of institution k's achieved concentration index $C_k(\mathbf{p})$. This index equals the institution's average program size, i.e. the average number of students per program:

$$C_k(\mathbf{p}) = \frac{Q_k(\mathbf{p})}{J_k}.$$

The program-related profits of institution k are therefore:

$$\begin{aligned}\pi_k(\mathbf{p}) &= \sum_{j=1}^{J_k} (p_{jk} + s_j - c_j)\, q_{jk}(\mathbf{p}) + rC_k(\mathbf{p}) - \sum_{j=1}^{J_k} F_{jk} \\ &= \sum_{j=1}^{J_k} p_{jk} q_{jk}(\mathbf{p}) + rC_k(\mathbf{p}) - \sum_{j=1}^{J_k} F_{jk},\end{aligned}$$

or simply the tuition fee revenues plus the revenues from the achieved concentration index minus the fixed costs.

Consumer surplus at a given price vector $\mathbf{p}$ is the sum of each student i's individual consumer surplus, $CS(\mathbf{p}) = \sum_{i=1}^{I} CS_i(\mathbf{p})$. Producer surplus is the sum of all institutions' program-related profits minus government subsidies. Since the subsidies are simply transfers from the government to the institutions, they cancel out, so that producer surplus reduces to tuition fee revenues minus variable costs

[52] This is consistent with our earlier work (Kelchtermans and Verboven, 2006), where we found very limited substitution to the outside good in response to price or cost increases.

[53] Institutions may also obtain other benefits, such as benefits from research or from raising the students' productivity (as modeled by Del Rey, 2001), or "prestige" (De Fraja and Iossa, 2001). While we do not rule out the presence of such objectives, we assume them to be separable from the direct program-related profits.

and fixed costs:

$$PS(\mathbf{p}) = \sum_{k=1}^{K} \sum_{j=1}^{J_k} (p_{jk} - c_j) q_{jk}(\mathbf{p}) - \sum_{k=1}^{K} \sum_{j=1}^{J_k} F_{jk}.$$

Total welfare is the sum of consumer and producer surplus, $W(\mathbf{p}) = CS(\mathbf{p}) + PS(\mathbf{p})$.

2.3.2 The effects of reducing supply diversity

It is convenient to define the elimination of study alternatives (programs/institutions) in terms of prohibitive tuition fee increases. The initial price vector is $\mathbf{p}^0$, and consists of identical tuition fees p^0 for all study alternatives. After the elimination of one or more study alternatives there is a new price vector $\mathbf{p}^1$, where the prices for the eliminated alternatives are replaced by infinitely high prices (so that their demands effectively become zero). We focus the exposition here on the elimination of one program j at one institution k, and denote this new price vector by $\mathbf{p}^1_{jk}$ (with the price for program j at institution k equal to infinity and the other prices equal to the initial level p^0). In our empirical analysis, we will also consider the elimination of one study program j at all institutions, as denoted by a price vector $\mathbf{p}^1_j$ (with infinite prices for program j at all institutions).

First, consider the effects of eliminating program j at institution k on the total demand (number of students) of institution k. A common measure is the diversion ratio DR_{jk} of the eliminated program j with respect to the other programs offered at institution k:

$$DR_{jk} = \frac{\sum_{j' \neq j}^{J_k} \left(q_{j'k}(\mathbf{p}^1_{jk}) - q_{j'k}(\mathbf{p}^0) \right)}{q_{jk}(\mathbf{p}^0)}.$$

This ratio is between zero and one, and measures the fraction of the students lost from the eliminated program j that flows back to other programs offered by the same institution k.[54] A high diversion ratio means that students have a strong preference for the institution rather than for the specific program. This may reflect

[54] The diversion ratio is often used in merger analysis (e.g. Shapiro, 1995), where it refers to the fraction of sales lost by brand A (due to a price increase) that is captured by brand B, as a first indicator of the competitive effects of a merger of brands A and B. It also frequently appears in the theory of access price regulation, where it is known as the displacement ratio.

high mobility costs, or simply the possibility that students perceive different study programs at the same institution as close substitutes.

Now consider the profit incentives for eliminating program j at institution k. One can verify that the change in profits from this variety reduction is:

$$\begin{aligned}\Delta\pi_{jk} &= \pi_k(\mathbf{p}^1_{jk}) - \pi_k(\mathbf{p}^0) \\ &= \underbrace{-(1-DR_{jk})p^0 q_{jk}(\mathbf{p}^0)}_{\text{tuition fee revenue loss}} + \underbrace{r\left(C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0)\right)}_{\text{change in concentration index}} + \underbrace{F_{jk}}_{\text{fixed cost saving}} .\end{aligned} \tag{2.1}$$

According to (2.1), the profit incentive from a variety reduction consists of three terms. The first term is the tuition fee revenue loss, and is clearly negative. The loss is smaller than the initial fee revenues from the eliminated alternative $p^0 q_{jk}(\mathbf{p}^0)$, since it accounts for the fact that some of the lost students may remain within the same institution ($DR_{jk} > 0$). The third term is positive and refers to the fixed cost savings associated with eliminating study program j. The second term captures the change in the concentration index, and may be positive or negative. One can easily verify that the concentration index increases, i.e. $C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0) > 0$, if and only if

$$q_{jk}(\mathbf{p}^0) < \frac{C_k(\mathbf{p}^0)}{1-DR_{jk}}.$$

Hence, the CI funding scheme provides a positive incentive for eliminating program j at institution k if it has a sufficiently low number of students. If the diversion ratio is zero, it provides a positive incentive if the number of students is below the current concentration index $C_k(\mathbf{p}^0)$. If the diversion ratio is positive, the system may provide a positive incentive even if the number of students is above the concentration index. The general message is that the system creates positive incentives to drop a program with a sufficiently small number of students, and especially if students have good substitution possibilities to other programs within that institution.

Finally, consider the welfare effects of eliminating program j at institution k. The effect on consumers is

$$\Delta CS_{jk} = CS(\mathbf{p}^1_{jk}) - CS(\mathbf{p}^0),$$

which is clearly negative since the program drop involves a (prohibitive) tuition fee increase for the eliminated program. Note that one can interpret $-\Delta CS_{jk}$ as the students' net willingness to pay for program j at institution k, i.e. the students' willingness to pay on top of the current tuition fees.[55] The effect of dropping program j at institution k on producer surplus is

$$\begin{aligned}\Delta PS_{jk} &= p^0 \sum_{k=1}^{K} \sum_{j=1}^{J_k} \left((q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0) \right) - \sum_{k=1}^{K} \sum_{j=1}^{J_k} \left(c_j (q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0) \right) + F_{jk} \\ &= -\sum_{k=1}^{K} \sum_{j=1}^{J_k} c_j \left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0) \right) + F_{jk},\end{aligned}$$

where the second equality follows from the fact that total demand is inelastic. The first term is the variable cost saving from an output reallocation effect following the program drop. It may be positive or negative depending on whether the other programs to which the students substitute have a lower or a higher variable cost than the eliminated program. The second term is a positive fixed cost saving.

The effect of a program cut on total welfare then consists of the following components:

$$\begin{aligned}\Delta W_{jk} &= \Delta CS_{jk} + \Delta PS_{jk} \\ &= \underbrace{CS(\mathbf{p}^1_{jk}) - CS(\mathbf{p}^0)}_{\text{consumer loss}} - \underbrace{\sum_{k=1}^{K} \sum_{j=1}^{J_k} c_j \left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0) \right)}_{\text{variable cost saving from output reallocation}} + \underbrace{F_{jk}}_{\text{fixed cost saving}} .\end{aligned} \tag{2.2}$$

Eliminating program j thus involves a negative effect on consumers, a positive or negative variable cost saving from output reallocation, and a positive fixed cost saving.

2.3.3 Drawing policy conclusions

A comparison of (2.1) and (2.2) clearly shows that the profit incentives and welfare effects of a program cut are not necessarily well-alligned. Our empirical analysis aims to assess this but faces the following main challenge. While it is possible to measure most profit and welfare components from our demand parameter estimates

[55] In the empirical analysis we will compare this with the willingness to pay for program j across all institutions (by considering the new price vector $\mathbf{p}^1_j$).

and our variable cost proxy, we do not observe the fixed cost savings involved in a program cut. We therefore proceed as follows.

- In a first step, we focus on the observable components of the profit and welfare effects, i.e. tuition fee revenue losses, the change in the concentration index, consumer losses, and the output reallocation effect.

- In the second step, we obtain reasonable lower and upper bounds on the fixed cost savings, and thereby provide at least sufficient conditions under which unilateral program cuts raise or lower total profits or welfare. It turns out that, in our application, this approach gives us conclusive anwsers on the profit and welfare effects of the CI funding system for a large number of cases.

More specifically, in the second step we make the following assumptions about the fixed costs of any program j at any institution k. First, we assume that fixed costs are positive, i.e. $F_{jk} > 0$ for all j, k. Second, we assume that institutions did not find it profitable to cut any of the offered programs under the old funding system, where the concentration index was not yet at work.[56] Inspecting (2.1), but without the term for the change in the concentration index, this amounts to assuming that $F_{jk} < (1 - DR_{jk})p^0 q_{jk}(\mathbf{p}^0)$ for any program j at any institution k. Intuitively, the fixed costs at any program and any institution are assumed to be less than the tuition fee revenue losses that would result from a program cut in the old funding system. These revenue losses are simply the actual revenues $p^0 q_{jk}(\mathbf{p}^0)$, adjusted for the diversion ratio.

Taken together, we thus bound the fixed costs of program j at institution k between two levels:

$$0 < F_{jk} < (1 - DR_{jk})p^0 q_{jk}(\mathbf{p}^0). \tag{2.3}$$

[56] This is in the spirit of the empirical IO literature on entry. From observing a certain program we can infer that it is profitable to supply it, implying an an upper bound on the fixed cost level. The empirical IO literature on free entry would often however go a step further. Under free entry, one could also infer that supplying additional programs would be unprofitable. This inference is not reasonable in our setting, since entry of addional programs is regulated, so institutions cannot simple add more programs to their portfolio as long as that is profitable.

Note that as the diversion ratio increases (becomes closer to 1), the upper bound on the fixed cost becomes tighter.

We can now combine the fixed cost bounds (2.3) with (2.1) and (2.2) to obtain the following *sufficient* conditions for the sign of the profit and welfare effects of unilateral program cuts, regardless of the level of fixed cost savings F_{jk}:

Proposition 1 *(i) The CI funding system does not provide a profit incentive to cut program j at institution k if $r\left(C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0)\right) < 0$, and does provide a positive profit incentive if $-(1-DR_{jk})p^0 q_{jk}(\mathbf{p}^0) + r\left(C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0)\right) > 0$.*

(ii) A program cut j at institution k is socially undesirable if $(1 - DR_{jk})p^0 q_{jk}(\mathbf{p}^0) + \Delta CS_{jk} - \sum_{k=1}^{K}\sum_{j=1}^{J_k} c_j\left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0)\right) < 0$, and desirable if $\Delta CS_{jk} - \sum_{k=1}^{K}\sum_{j=1}^{J_k} c_j\left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0)\right) > 0$.

The effects of the CI funding system can therefore be classified in four natural cases, as summarized in Table 2.3. The top left cell shows the "desirable status quo" cases, under which a unilateral program cut is neither profitable nor socially desirable under the CI funding system. The top right cell shows the "undesirable status quo" cases, under which a unilateral program cut is not profitable under the CI funding system although it would be socially desirable. The bottom left cell shows the "undesirable reform" cases, under which a program cut is profitable although it is not socially desirable. Finally, the bottom right cell shows the "desirable reform" cases, under a unilateral program cut is both profitable and socially desirable. Our empirical analysis will show that it is possible to unambiguously classify many of the unilateral program cuts into one these categories, even without observing the actual fixed cost savings F_{jk}.

2.4 Empirical framework

To estimate the various components of the profit and welfare effects, we adopt a logit demand model for the various study programs at the different institutions. The logit model is well-suited to deal with our large data set, which consists of $37,481$ students choosing one out of the 562 study alternatives (programs/institutions). A main computational advantage is that it enables us to obtain consistent maximum likelihood estimates of the demand parameters by sampling over the large number of study alternatives. This is considerably more efficient than sampling over the individuals.[57]

Our logit model does not include an outside good (a "no-study alternative"), so that total demand is perfectly inelastic with respect to price or with respect to eliminating an alternative. Kelchtermans and Verboven (2006) include an outside good in a nested logit framework. While their analysis encovers some interesting determinants on the decision whether or not to start with higher education, they find that students are extremely price inelastic. We therefore chose to adopt the computationally simpler logit model without an outside good. This is especially convenient since we analyze the study alternatives at a much more disaggregate level than Kelchtermans and Verboven (2006).

2.4.1 Indirect utility

A student i's conditional indirect utility for study program j at institution k consists of a deterministic component V_{ijk} and a random component ε_{ijk}. The deterministic component V_{ijk} depends on the expected benefits from studying, including monetary returns in the form of increased future salaries and non-monetary benefits from education, and on the expected costs, i.e. the monetary costs in the form of tuition fees and travel costs, and the non-monetary costs of studying. We take the following specification:

$$V_{ijk} = \beta_{jk} + w_i'\gamma_{jk} + w_i'\alpha(y_i - p_{jk} - g(x_{ik})), \qquad (2.4)$$

where w_i is a vector of individual characteristics (sex, age, high school background, etc.), y_i is student i' s annual income, p_{jk} is the tuition fee for study program j at

[57] Sampling over alternatives in non-logit models does not generally give consistent maximum likelihood estimates. Bierlaire et al. (2006) show that it is still possible to obtain consistent maximum likelihood estimates in "block additive generalized extreme value models", which includes the logit but not the nested logit model. Kelchtermans and Verboven (2006) show how to sample over alternatives in a nested logit model using a sequential procedure. Most recently, Fox (2007) has proposed a maximum score estimator to obtain consistent estimates based on a subset of alternatives for a general class of discrete choice models including random coefficients (or mixed) logit models. However, given the richness of our data set, the need for controlling for additional unobserved student heterogeneity appears to be lower here than in other applications.

institution k, and $g(x_{ik})$ is an implicit price because of the annual travel costs x_{ik} of student i to institution k.

The first two terms in (2.4) may in principle include a full set of alternative-specific intercepts β_{jk} and slope vectors γ_{jk}. In practice, such flexibility would imply a very large number of parameters to be estimated because of the large number of alternatives, to be interacted with the individual characteristics in the vector w_i. We will therefore specify alternative-specific effects β_{jk} and γ_{jk} to depend on a more limited but still rich set of alternative characteristics (e.g. program type or field, institution's religious affiliation, etc.).

The third term in (2.4) refers to the utility from the consumption on goods other than the study alternative, after spending the tuition fee p_{jk} and an implicit price $g(x_{ik})$, which is an increasing function of the annual travel costs x_{ik} of student i to institution k. The parameter vector α captures the determinants of the marginal utility of income and is important to convert utility in monetary terms and conduct our welfare analysis. Each student either commutes or goes on residence. If she commutes, her implicit price for alternative j is simply the annual travel cost $g(x_{ik}) = x_{ik}$. If she goes on residence, she saves a fraction ϕ of the trips, but pays an extra annual cost on rent r_k, so that her implicit price becomes $g(x_{ik}) = (1-\phi)x_{ik} + r_k$. A cost-minimizing student thus commutes if and only if she is located sufficiently closely to institution k, i.e. $\phi x_{ik} \leq r_k$. The deterministic component of utility (2.4) can then be written as:

$$V_{ijk} = \beta_{jk} + w_i'\gamma_{jk} + w_i'\alpha\,(y_i - p_{jk} - x_{ik}) + w_i'\alpha(\phi x_{ik} - r_k)\,I(\phi x_{ik} - r_k), \quad (2.5)$$

where $I(\cdot)$ is an indicator function equal to 1 if the expression inside the brackets is positive, and equal to 0 otherwise. Utility therefore decreases in the annual travel costs x_{ik} in a piecewise linear way: at a steeper rate $w_i'\alpha$ for low values of x_{ik} (when the student commutes), and at a flatter rate $w_i'\alpha\phi$ for high values of x_{ik} (when the student goes on residence).

2.4.2 Estimation and data set

Each student i chooses the study program j at institution k that maximizes random utility $V_{ijk} + \varepsilon_{ijk}$, where ε_{ijk} takes the extreme value distribution. This results in the familiar logit choice probabilities for each student i for each progam j at institution k. It also gives the standard expressions for expected consumer surplus for each student i; see for example Train (2003) for details.

The logit choice probabilities can be used to construct the likelihood function and estimate the parameters. There are, however, practical difficulties due to the size of our data set.

- We observe a very large number of students ($37,481$), i.e. all incoming first-year students in Flanders in 2001.
- Each student can choose from a very large number of study alternatives (562), i.e. the various programs offered across 53 different campuses.
- We observe a very large set of study characteristics, to be interacted with many student characteristics.

The logit model can overcome these difficulties and generate consistent maximum likelihood estimates by sampling over the study alternatives. Specifically, for each student we sample a choice set of 20 alternatives, including the chosen alternative plus a random sample of 19 other study alternatives. This sampling approach is considerably more efficient than sampling over individuals, in particular to identify the utility determinants of some relatively unpopular alternatives with few observations. It also provides considerably richer substitution parameters than aggregating over groups of study alternatives.[58]

[58] Furthermore, since we do not exploit observable variation across elemental alternatives (e.g. nursing) within a study field (e.g. biomedical vocational), we can aggregate the 562 elemental program/institution alternatives up to 226 field/type/institution alternatives. In the logit model this can be done by simply including the log of the number of elemental alternatives within each aggregate alternative as an additional variable in the utility specification. This approach follows Ben-Akiva and Lerman (1985), as applied by Kelchtermans and Verboven (2006) for a much more aggregate version of the model.

Our data set comes from the Flemish Ministry of Education, and has information on:

- Student characteristics (w_i). This consists of demographic information, i.e. sex, nationality and religious affiliation of the high school; and information on scholastic ability, i.e. years of repetition in high school, the type of high school (general, technical or professional) and the study program followed at high school (e.g. mathematics, languages).

- Travel costs (x_{ik}). From information on students' and institutions' locations, we compute the distance per trip d_{ik} (in km) and the travel time per trip t_{ik} (in min) for every student i to every institution k. We then set the annual travel costs x_{ik} (in Euro) to $x_{ik} = 75d_{ik} + 40t_{ik}$.[59]

- Study alternative characteristics (entering β_{jk} and γ_{jk}). This consists of the following variables: the institution's religious orientation, the study program type (one-cycle and two-cycle vocational programs at colleges, and academic programs at universities) and the ten study fields discussed in section 2 (architecture, engineering, etc.).

Following the utility specification (2.5), we interact the student characteristics (w_i) with both the travel costs (x_{ik}) and the study alternative characteristics (in γ_{jk}). Table 2.4 provides summary statistics on the student characteristics and travel costs (rows), by a few main study characteristics (columns). We refer to Kelchtermans & Verboven (2006) for a more extensive discussion of the data set.

2.4.3 Parameter estimates

Tables 2.5, 2.6 and 2.7 present the maximum likelihood estimates of the logit model. We briefly discuss these estimates to give an idea of the determinants un-

[59] This follows Kelchtermans and Verboven (2006) and assumes that a commuter engages in 10 trips per week during 30 weeks of the year, at a transportation cost of 0.25 Euro/km and an opportunity cost of time of 8 Euro/hour. The latter amount corresponds to the typical wage for student jobs.

derlying the study choice process. It is however possible to directly move to section 2.5.1, where we discuss the demand, profit and welfare effects from reducing supply based on our parameter estimates.

Table 2.5 gives a general overview of the estimated specification and highlights the role of travel costs in the study choice process ($w_i'\alpha$ and ϕ). Travel costs have a negative and highly significant effect on utility (an estimated intercept in α of -6.19 and a t-statistic of -28.54). There are differences across individuals. For example, students from a catholic high school or with a classical languages background are less cost sensitive and consequently travel further. In contrast, students with several repetitions at high school or with a technical (non-product focused) high school background are more cost sensitive and therefore study more nearby their homes. Furthermore, the parameter $\phi = 0.49$ shows that the effect of travel costs decreases significantly in distance: distant student go on residence and save 49% on the travel costs (to be traded off against their fixed renting costs). Finally, the size factor parameter is close to 1, indicating that the study programs within a program field are relatively heterogeneous (i.e. controlling for observed choice determinants, preferences are not much stronger correlated for programs of the same field than for programs of different fields).

Tables 2.6 and 2.7 show how individuals value the various characteristics of the study alternatives ($w_i'\gamma_{jk}$).[60] The first column of Table 2.6 shows the preferences for catholic institutions. Most notably, students from a catholic high school still tend to value catholic colleges and universities higher than other students, suggesting continuing strong links between the catholic networks at high school and higher education level. The second and third columns of Table 2.6 show the impact of nationality and the specific high school background on the utility for academic or two-cycle vocational programs. For example, foreign students tend to prefer the academic and two-cycle vocational programs over the one-cycle vocational programs. This is also true for students with a general high school background in

[60] These results extend Kelchtermans and Verboven (2006) by (1) considering more detailed study fields (Table 2.6), and (2) adding richer interaction terms between the study fields/types and the student characteristics (Table 2.7). Nevertheless, several parameters are imposed to zero because of a too low number of observations on some of the interactions.

classical languages and/or mathematics. The remaining columns of Table 2.6 show the impact of nationality and high school background on the utility for the specific study fields (cultural studies being the base category). Foreigners are more likely to opt for engineering or economics & business. Furthermore, the specific general high school background is closely related to the valuation for the study fields at higher education institutions. For example, students with a science of mathematics general high school background have a strong preference for science or engineering programs and not for programs in languages or culture (the base category). The reverse is true for students with a general high school background in classical languages.

Table 2.7 presents the role of the other student characteristics (sex, years of repetition and type of high school) on the study fields, broken down by the program type (one-cycle and two-cycle vocational, and academic). For example, male students have a higher preference for engineering and economics & business programs, regardless of the type of higher education. At the same time, they have a lower preference for medicine & paramedics but only if this is of the one-cycle vocational type (which primarily consists of nursing programs). As another example, students who experienced a year of repetition in high school have a lower utility from participating in architecture and engineering but only if this is of the academic type. Such students also prefer economics & business or medicine & paramedics of the one-cycle vocational type, rather than of the two-cycle vocational or academic types. Students with an intellectually more demanding general high school background tend to prefer the academic and two-cycle program fields over the counterparts of the one-cycle program fields.

2.5 The effects of reducing supply diversity

Based on our parameter estimates, section 2.5.1 presents the demand, profit and welfare effects from reducing supply diversity, without considering the fixed cost savings. Section 2.5.2 then assesses the total profit and welfare effects, based on our obtained bounds for the fixed cost savings (2.3). This enables us to draw conclusions regarding the profit incentives and social desirability of reducing supply diversity in the CI funding system.

2.5.1 Demand, profit and welfare effects

We first present the demand effects from unilateral program cuts at individual institutions. We use our parameter estimates to calculate diversion ratios. As discussed earlier, the diversion ratio measures the fraction of students that are retained by other programs of the same institution when a specific program is eliminated. Table 2.8 lists the average diversion ratios resulting from unilateral program cuts, shown by study field[61]. The diversion ratios tend to be clearly higher at universities than at colleges (average across all fields of 28% versus 19%). Universities would thus loose comparatively fewer students after individual program cuts. This is due to their larger size and less competition. There are some interesting differences in the diversion ratios between the fields. For example, the diversion ratio is particularly low for language programs at colleges (8%), indicating that students do not perceive other programs offered at the same institution as good substitutes. At the other extreme, the diversion ratio is over 30% for architecture, engineering, medicine and education sciences at universities. Students thus find fairly good substitution possibilities within the same university for programs from these fields.

Table 2.9 shows how these substitution effects from the program cuts translate into two of the profit components: tuition fee revenues and revenues from the CI funding scheme. (The third profit component, i.e. fixed cost savings, is addressed in the next subsection.) The tuition fee revenues decrease in all fields (third and fourth columns of Table 2.9), but by less than the current tuition fee revenues (first and second columns). This follows directly from the diversion ratios, i.e. the fact that students may substitute to other programs within the university after a program cut. The revenue changes from the concentration index based funding scheme may or may not compensate for these tuition fee revenue losses (fifth and sixth columns). Program cuts from large fields such as educational sciences would

[61] For example, the first row shows the average fraction of students that is retained when a college or university drops one of its architecture programs.

result in a lower concentration index and hence create additional revenue losses. In contrast, program cuts from the smaller fields, such as bio-engineering at colleges or sciences and medicine at universities, result in large increases in the concentration index, generating revenue gains that actually outweigh the tuition fee revenue losses. For those cases, the funding system provides incentives to cut programs even without any fixed cost savings.

Table 2.10 shows the effects of unilateral program cuts on two of the welfare components: consumer surplus and variable costs. (The third component is again fixed costs and addressed in the next subsection.) The consumer surplus effects are evidently always negative (first two columns). This is especially so for the larger programs at colleges and universities. Recall that the absolute value of these consumer surplus effects may also be interpreted as the students' net willingness to pay for the eliminated program, i.e. their willingness to pay on top of the paid tuition fees. This willingness to pay is usually quite large, for some fields it is three to four times larger than the students' actual tuition fee expenditures (shown in Table 2.9).[62] This is due to a low student mobility and willingness to travel to other institutions, as found earlier in our empirical analysis. The variable cost savings, stemming from output reallocation, may also be negative (third and fourth column of Table 2.10). This is the case for cutting programs with low variable costs, such as economics&business or cultural programs, which both cause substitution towards more expensive programs. The variable cost savings may, however, also be positive, most notably for the high variable cost programs such as science and medicine at universities. In these cases the variable cost savings even outweigh the consumer surplus losses so that the total gross welfare changes are positive (last two columns of Table 2.10). Hence, eliminating these programs would result in a total welfare gain even without any fixed cost savings. Program cuts from other fields, however, usually involve negative gross welfare effects, even when variable cost savings are

[62] For example, the net willingness to pay for a study program in engineering at universities is on average 522,386 €, which is about 3.5 times higher than the actual tuition fee expenditures (148,479 €). For bio-engineering at colleges, the net willingness to pay is only about double than the actual tuition fee expenditures (39,502 € versus 20,252 €). For language programs at universities, the net willingness to pay is less than what students currently already pay in fees (69,663 € versus 75,208 €).

positive. They would therefore require sufficient fixed cost savings for total welfare to increase. Whether this is indeed the case, will be addressed separately in the next subsection, based on our estimated bounds on the fixed cost savings.

To put the above welfare discussion in perspective, Table 2.11 presents the analogue welfare effects from *joint* program cuts, i.e. program cuts common for all institutions offering the same program. We focus our discussion on the consumer surplus losses (first two columns). As expected when many programs are eliminated at the same time, the consumer surplus losses are considerably larger than those from the unilateral program cuts in Table 2.10. What is more interesting, however, is that the consumer surplus losses from joint program cuts are disproportionally larger than those from unilateral program cuts. Consider, for example, engineering programs at colleges. These are available at 25 college campuses (Table 2.1), but the consumer surplus loss is more than 40 times larger under a joint program cut than under a unilateral program cut (loss of 4,977,878 € versus 116,347 €). This motivates our focus on unilateral program cuts which may reduce inefficient duplication of fixed costs across multiple campuses, rather than on joint program cuts which cause disproportionate consumer surplus losses.

2.5.2 Evaluation of the funding system reform

To assess the total profit and welfare effects of the CI funding system, we now introduce the fixed cost bounds derived in (2.3). Based on these bounds, Proposition 1 showed that the CI funding system provides no incentive to cut a program if this reduces the concentration index, while it does provide such an incentive if the additional revenues from an increase in the concentration index outweigh the tuition fee losses. Similarly, Proposition 1 showed that a program cut is socially desirable if the sum of the consumer surplus losses and the variable cost savings from output reallocation is positive; a program cut is undesirable if the sum of consumer surplus losses, variable cost savings and tuition fee revenue losses is negative. Table 2.3 provided the corresponding classification of program cuts in desirable status quo, undesirable status quo, desirable reform and undesirable reform cases.

Table 2.12 applies this classification. It counts how many out of the 225 possible program cuts can be unambiguously classified into one of these four cases, using our estimated fixed cost bounds and the profit and welfare components of the previous subsection. We begin with the left column. This shows that for the large majority of cases (206 out of 225, or over 90%) it is socially undesirable to cut programs at individual institutions. This striking result follows from the low student mobility and the correspondingly large total willingness to pay for programs at individual institutions. The large consumer surplus losses from program cuts are typically not compensated by sufficient variable of fixed cost savings. The individual cells show the profit incentives for these undesirable program cuts. We can unambiguously classify at least 85 out of the 225 programs as desirable status quo cases, i.e. the CI funding system rightly does not give a profit incentive to cut the program. However, there is also a quite large number of 63 undesirable reform cases, where the system actually does provide the wrong profit incentive to cut the program.[63] In sum, for about 30% (63 cases) to possibly 60% (63+58 cases) of the 206 cases where it is undesirable to reduce supply diversity, the CI funding system wrongly provides an incentive to do so.

The right column of Table 2.12 shows that it would be socially desirable to cut supply diversity in a small minority of 16 cases (less than 10%). But the CI funding system actually provides the good profit incentives to cut supply for only 8 of these 16 cases. It fails to provide the proper incentives in 1 out of 16 cases. It fails to provide the proper incentives for at least 1 and up to 8 of the 16 cases.[64]

The overall conclusion is rather pessimistic about a funding system based on a concentration index. Its main motivation was to provide incentives to reduce supply diversity in a decentralized way. However, it fails to improve total welfare in two respects. First, for the majority of cases (206) reducing supply diversity is not

[63] The middle cell of the left column shows the remaining 58 cases for which we can unambiguously conclude that a program cut is socially undesirable, but for which we cannot determine the sign of the profit incentive without further information on fixed costs.

[64] For the remaining 7 cases the sign of the profit incentive cannot be determined unambiguously without further fixed cost information. Furthermore, the middle column shows the cases for which the sign of the total welfare effects cannot be determined without further information on fixed costs. Fortunately, the number of cases in this column is small, showing that our bounds approach is quite informative on the total welfare effects.

actually socially desirable, but the incentives are nevertheless given for about half of these cases. Second, while for a minority of cases (16) reducing supply diversity would be socially desirable, the proper incentives are only given in half of these cases. From a methodological perspective, our approach to bound the fixed costs shows that it is possible to draw unambiguous total welfare conclusions in quite a large number of cases (85+63+1+8=157 out of 225), even without knowing the actual level of the realized fixed cost savings.

2.6 Conclusions

We have analyzed the profit and welfare effects of reducing supply diversity in higher education. The background was a funding system reform proposed by te Flemish government, where universities and colleges would obtain part of their subsidies based on their achieved concentration index (i.e. average number of students per program). A first main lesson from our analysis is that the social desirability of reducing supply diversity is considerably more limited than commonly thought. Social welfare increases in only a small minority of cases (less than 10% of the possible program cuts). The large majority of hypothetical program cuts (more than 90%) involves a reduction in social welfare. While there may be fixed cost savings as well as variable cost savings from cutting the relatively expensive programs, these typically do not outweigh the large consumer losses because of a relatively low student mobility. Put differently, while there is frequent duplication of fixed costs because programs are available at multiple campuses, this is not inefficient because of the students' limited willingness to travel to other campuses.

The second main lesson is that a funding system based on the institution's concentration index often misses its purpose. There tends to be a severe mismatch between the social desirability to reduce supply diversity and the actual incentives provided. The idea behind the suggested system was to encourage institutions to cut the relatively small programs (since this would raise the institutions' concentration index, i.e. average number of students per program). However, we find that in about half of the cases were program cuts are not desirable, the system nevertheless creates the incentives to do so. Furthermore, for the minority of cases where program cuts are actually desirable, the proper incentives are often not given. These findings emphasize the complex task of governments in regulating the supply of higher education. They also serve as a word of caution towards the various other initiatives that have recently been taken in public systems of higher education, e.g. other funding systems (designed to jointly operate certain study programs between institutions), incentives to form mergers or associations between institutions, etc.

Our analysis is based on a simple economic framework, illuminating the role of consumer surplus losses, variable cost savings and fixed cost savings, and the funding system. From a methodological perspective, it shows how it is possible to reach unambiguous conclusions about profit incentives and welfare by deriving bounds on the fixed costs, without requiring information on the actual fixed costs. At the same time, our analysis is based on a number of assumptions. First, we do not take into account income effects. It is possible that some program cuts hurt low income groups more than others, which may affect the relative social desirability of certain program cuts. Second, we do not take into account the social cost of public funds. To the extent that these are important, the social desirability to cut supply diversity would be higher. Third, we have looked at undergraduate education. It is possible that the desirability for variety reduction is greater in graduate education where student willingness to travel may be considerably greater. Finally, we have assumed that the private gains from higher education (consumer surplus) coincides with the social gains. In practice, the social gains may exceed the private gains because of positive spillovers (non-appropriability of the returns to education). To the extent that such spillovers exist and apply to all study programs, this would strengthen the conclusions regarding the relative undesirability of reducing program diversity. However, to the extent that spillovers are program-specific, our conclusions may need modification. For example, if students from sciences programs provide strong spillovers (for example to sectors employing low-skilled labour), then it may no longer be desirable to cut some of these programs based on the argument that the variable cost savings outweigh the consumer surplus losses. Unfortunately, it is not possible to integrate this formally in our analysis since the evidence on the extent of spill-overs is limited and mixed, especially at the level of the individual study programs (see Jacobs and van der Ploeg's review paper, 2005).

2.7 Tables

Table 2.1: Supply of Higher Education in Flanders (2001)

	Colleges			
	Campuses	Study programs	Students	Students/ study program
Total	44	414	25,182	61
by study field				
Architecture	9	11	912	83
Engineering	25	76	4,425	58
Science	n/a	n/a	n/a	n/a
Economics & Business	22	105	7,853	75
Education Science	26	67	6,065	91
Other Social Sciences	13	15	1,572	105
Medicine & Paramedics	23	54	1,904	35
Bio-engineering	15	26	644	25
Languages	5	5	738	148
Cultural Studies	10	55	1,069	19
	Universities			
	Campuses	Study programs	Students	Students/ study program
Total	9	148	12,299	83
by study field				
Architecture	3	3	198	66
Engineering	3	3	834	278
Science	7	33	1,169	35
Economics & Business	7	12	1,700	142
Education Science	3	6	711	119
Other Social Sciences	6	19	3,701	195
Medicine & Paramedics	6	19	933	49
Bio-engineering	6	13	1,177	91
Languages	6	17	842	50
Cultural Studies	6	23	1,034	45

Own calculations based on a dataset from the Flemish Ministry of Education

Table 2.2: Variable subsidies per student in Euros

	Colleges	Universities
Average	3,203	4,075
Architecture	3,527	5,290
Engineering	3,594	5,290
Science	n/a	5,290
Economics & Business	2,333	2,921
Education Science	3,633	3,767
Other Social Sciences	3,220	2,785
Medicine & Paramedics	3,711	5,444
Bio-engineering	3,721	4,527
Languages	2,760	2,719
Cultural Studies	2,331	2,713

The base subsidy for a study program is 2,300 Euro. Weighting factors are applied depending on the resource-intensiveness of the program as indicated in the new funding scheme for higher education. We report student-weighted averages of subsidies per study field for colleges and universities

Table 2.3: Possible profit incentives and welfare effects of unilateral program cuts

	Welfare Effect	
Profit Incentive	$(1-DR_{jk})p^0 q_{jk}(p^0) + \Delta CS_{jk} - \sum_{k=1}^{K}\sum_{j=1}^{J_k} c_j \left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0)\right) < 0$	$\Delta CS_{jk} - \sum_{k=1}^{K}\sum_{j=1}^{J_k} c_j \left(q_{jk}(\mathbf{p}^1_{jk}) - q_{jk}(\mathbf{p}^0)\right) > 0$
$r\left(C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0)\right) < 0$	desirable status quo	undesirable status quo
$-(1-DR_{jk})p^0 q_{jk}(p^0) + r\left(C_k(\mathbf{p}^1_{jk}) - C_k(\mathbf{p}^0)\right) > 0$	undesirable reform	desirable reform

Table 2.4: Summary statistics of 2001 eligible pupils

	All students	College	University	Non-catholic	Catholic
Demographic (w_i)					
male	0.45	0.45	0.45	0.47	0.43
foreign	0.01	0.01	0.01	0.02	0.01
catholic high school	0.78	0.79	0.76	0.67	0.87
Ability (w_i)					
years of repetition	0.36	0.46	0.16	0.40	0.34
	(0.95)	(0.99)	(0.83)	(1.05)	(0.87)
general high school	0.60	0.44	0.94	0.63	0.58
classical languages	0.14	0.05	0.33	0.15	0.13
modern languages	0.24	0.22	0.27	0.23	0.24
economics	0.19	0.19	0.17	0.17	0.20
sciences	0.20	0.11	0.40	0.24	0.18
mathematics	0.30	0.15	0.60	0.34	0.27
technical high school	0.33	0.47	0.04	0.29	0.35
'product'-focused	0.12	0.17	0.02	0.11	0.12
Mobility (x_{ik})					
Distance (kms) by road to campus	34.71	30.96	42.38	35.73	33.90
	(28.17)	(25.65)	(31.37)	(28.19)	(28.13)
Time (mins) by road to campus	30.74	28.33	35.67	32.13	29.64
	(17.33)	(16.2)	(18.47)	(17.59)	(17.03)
Travel cost to campus (x10,000€)	0.38	0.35	0.46	0.40	0.37
	(0.28)	(0.25)	(0.31)	(0.28)	(0.28)
Number of observations	37,481	25,182	12,299	16,557	20,924

Standard errors for the continuous variables are in parentheses. Demographic and ability data are based on the dataset from the Flemish Ministry of Education; mobility statistics are based on own calculations using postal code information.

Table 2.5: Parameter estimates logit model: travel cost parameters

Parameter	Estimate	t
Travel cost (α_i)		
intercept	-6.19*	(-28.54)
φ	0.49*	(45.20)
male	0.1	(1.32)
foreign	-0.26	(-0.68)
catholic high school	0.43*	(4.62)
years of repetition	-0.2*	(-3.33)
general high school[1]	0.13	(0.67)
classical languages	0.49*	(4.00)
modern languages	-0.28*	(-2.44)
economics	-0.45*	(-3.43)
sciences	0.13	(1.09)
mathematics	0.07	(0.60)
technical high school[1]	-1.72*	(-9.69)
'product'-focused	1.38*	(9.98)
Size factor	0.91*	(49.63)
Slope parameters (γ_j)		
Catholic Institution[2]	*included, see table 2.6*	
Academic program[3]	*included, see table 2.6*	
Vocational long program[3]	*included, see table 2.6*	
Study field[4]	*included, see table 2.6*	
Academic program x Study field[5]	*included, see table 2.7*	
Vocational long program x Study field[5]	*included, see table 2.7*	
Fixed effects (β_j)	*included, see table 2.6*	
Observations	732,040	
number of individuals	*36,602*	
number of sampled alternatives	*20*	
Log likelihood	-51,816	

t-statistics in parentheses. * statistical significance at 5% level

[1] base category = professional/arts secondary high school

[2] base category = non-catholic study option

[3] base category = vocational short study option

[4] base category = cultural studies

[5] base category = vocational short x cultural studies

Table 2.6: Parameter estimates logit model: valuation of a study option's catholic orientation, type of higher education and study field

Parameter	Catholic institution[1]	Type of Higher Education[2]		Study field[3]								
		Academic	Vocational Long	Arch	Eng	Science	Econ & Business	Educ	Other Social Sc	Med & Paramed	Bio-Eng	Lang
intercept	-0.70*	0.35	-0.51*	-0.16	-3.25*	-2.91*	-2.74*	-1.05*	-1.52*	-3.25*	-3.20*	-2.39*
	(-5.80)	(1.23)	(-2.92)	(-0.68)	(-14.04)	(-5.42)	(-12.93)	(-5.00)	(-6.58)	(-12.28)	(-9.17)	(-6.55)
male	-0.01	*See higher-order interaction terms in table 2.7*										
	(-0.19)											
foreign	-0.38*	0.92*	0.56*	0.43	0.97*	0.52	0.77*	-0.07	0.55	0.73	0.53	0.60
	(-2.47)	(3.97)	(2.34)	(0.91)	(2.51)	(0.95)	(2.12)	(-0.18)	(1.44)	(1.82)	(1.09)	(1.43)
years of repetition	-0.13*	*See higher-order interaction terms in table 2.7*										
	(-5.14)											
catholic high school	1.44*	*See higher-order interaction terms in table 2.7*										
	(38.08)											
general high school[4]	-0.05	*See higher-order interaction terms in table 2.7*										
	(-0.66)											
classical languages	0.18*	1.73*	0.67*	-0.37*	-0.63*	-0.74*	-0.49*	-0.64*	-0.44*	-0.20	-0.24	0.49*
	(3.46)	(22.25)	(6.91)	(-2.41)	(-4.94)	(-4.92)	(-4.33)	(-5.16)	(-4.04)	(-1.62)	(-1.82)	(3.92)
modern languages	-0.07	-0.02	0.25*	-0.07	-0.08	0.24	0.37*	-0.08	0.29*	-0.10	0.22	1.16*
	(-1.43)	(-0.37)	(3.08)	(-0.46)	(-0.62)	(1.35)	(3.48)	(-0.74)	(2.78)	(-0.79)	(1.45)	(9.95)
economics	0.04	0.33*	0.77*	0.07	0.02	0.00	1.73*	0.61*	0.30*	0.42*	-0.01	-0.23
	(0.82)	(4.49)	(8.49)	(0.40)	(0.13)	(0.01)	(13.85)	(4.54)	(2.30)	(2.86)	(-0.06)	(-1.60)
sciences	-0.07	1.27*	1.05*	0.67*	1.25*	1.25*	0.43*	0.81*	0.02	1.48*	1.92*	-0.30*
	(-1.34)	(17.73)	(11.98)	(4.45)	(9.92)	(8.04)	(3.76)	(6.69)	(0.14)	(11.87)	(13.89)	(-2.20)
mathematics	0.04	1.89*	1.35*	1.91*	2.54*	2.26*	1.69*	0.94*	0.25*	1.20*	2.18*	0.25*
	(0.88)	(29.11)	(16.73)	(12.87)	(20.20)	(13.12)	(15.70)	(8.16)	(2.28)	(9.82)	(14.46)	(2.05)
technical high school[4]	-0.28*	*See higher-order interaction terms in table 2.7*										
	(-3.88)											
product-focused	-0.01	0.67*	0.60*	1.51*	3.18*	1.51*	-0.30	-0.14	-0.56*	0.00	2.61*	-1.76*
	(-0.14)	(4.56)	(4.96)	(6.73)	(16.52)	(4.46)	(-1.60)	(-0.72)	(-2.68)	(-0.02)	(11.95)	(-3.58)

t-statistics in parentheses. * statistical significance at 5% level
[1] base category = non-catholic study option
[2] base category = vocational short study option
[3] base category = cultural studies
[4] base category = professional/arts high school

Table 2.7: Parameter estimates logit model: valuation of study fields within the higher education type

	Academic Higher Education[1] x									
Parameter	Arch	Eng	Science	Econ & Business	Educ	Other Social Sciences	Med & Paramed	Bio Eng	Lang	Cult
male	0.64	2.45*	1.45*	1.17*	-0.23	0.05	-0.19	0.02	-0.16	0.57
	(1.70)	(6.80)	(4.16)	(3.40)	(-0.64)	(0.15)	(-0.53)	(0.05)	(-0.46)	(1.64)
years of repetition	-0.99*	-0.98*	-0.16	-0.03	0.15	0.37*	-0.15	-0.15	0.21	0.26
	(-3.36)	(-4.66)	(-0.92)	(-0.21)	(0.85)	(2.34)	(-0.79)	(-0.80)	(1.16)	(1.67)
catholic high school	-0.28	-0.36	-0.72*	-0.68*	-0.68*	-0.80*	0.00	-0.22	-0.34	-0.93*
	(-0.73)	(-1.06)	(-2.17)	(-2.05)	(-2.01)	(-2.47)	(-0.01)	(-0.65)	(-1.02)	(-2.84)
general high school[2]	1.71*	4.25*	2.32*	4.09*	3.49*	4.82*	3.83*	3.28*	3.37*	1.81*
	(3.28)	(8.87)	(3.86)	(9.58)	(8.25)	(11.99)	(8.26)	(6.26)	(7.01)	(5.26)
technical high school[2]	0.15	2.20*	2.21*	3.45*	2.79*	3.56*	3.35*	2.05*	2.33*	0.86*
	(0.20)	(3.80)	(3.37)	(6.85)	(5.53)	(7.75)	(6.17)	(3.38)	(4.10)	(2.01)

	Vocational Long Higher Education[1] x									
Parameter	Arch	Eng	Science	Econ & Business	Educ	Other Social Sciences	Med & Paramed	Bio Eng	Lang	Cult
male	0.39	2.00*	n/a	0.96*	n/a	n/a	-0.17	0.99*	-0.34	0.64
	(1.10)	(5.78)		(2.75)			(-0.46)	(2.23)	(-0.96)	(1.83)
years of repetition	0.01	-0.22	n/a	-0.03	n/a	n/a	0.35	-1.33*	0.19	0.01
	(0.06)	(-1.36)		(-0.17)			(1.85)	(-2.79)	(1.10)	(0.04)
catholic high school	0.35	0.24	n/a	0.04	n/a	n/a	-0.51	0.35	-0.09	-0.08
	(0.98)	(0.74)		(0.12)			(-1.39)	(0.71)	(-0.25)	(-0.24)
general high school[2]	0.19	1.46*	n/a	2.11*	n/a	n/a	2.54*	1.04	3.33*	-0.95*
	(0.46)	(3.44)		(5.01)			(5.31)	(1.35)	(7.00)	(-2.83)
technical high school[2]	0.00	1.60*	n/a	3.03*	n/a	n/a	4.10*	1.43	3.35*	-1.01*
	(0.00)	(3.37)		(6.45)			(7.79)	(1.65)	(6.36)	(-2.47)

	Vocational Short Higher Education[1] x								
Parameter	Arch	Eng	Science	Econ & Business	Educ	Other Social Sciences	Med & Paramed	Bio Eng	Lang
male	0.09	1.91*	n/a	0.74*	-0.37	-0.58	-1.26*	-0.31	n/a
	(0.26)	(5.51)		(2.18)	(-1.10)	(-1.67)	(-3.63)	(-0.88)	
years of repetition	0.20	0.20	n/a	0.40*	0.26	0.41*	0.37*	0.16	n/a
	(1.24)	(1.31)		(2.72)	(1.77)	(2.70)	(2.38)	(0.96)	
catholic high school	-0.26	1.58*	n/a	-0.27	-0.38	-0.48	-0.31	-0.18	n/a
	(-0.79)	(3.84)		(-0.85)	(-1.19)	(-1.48)	(-0.96)	(-0.51)	
general high school[2]	-0.02	0.56	n/a	1.58*	1.52*	2.56*	2.64*	1.35*	n/a
	(-0.05)	(1.55)		(4.71)	(4.57)	(7.41)	(7.26)	(3.12)	
technical high school[2]	0.72	-0.34	n/a	3.40*	2.63*	3.00*	3.75*	2.85*	n/a
	(1.72)	(-1.05)		(8.54)	(6.63)	(7.32)	(8.93)	(6.08)	

t-stats between parentheses. * statistical significance at 5% level
[1] base category = vocational short x cultural studies
[2] base category = professional/arts high school

Table 2.8: Average diversion ratios resulting from unilateral program cuts, by study field

Study field	Colleges	Universities
Architecture	0.11	0.36
Engineering	0.15	0.31
Science	n/a	0.29
Economics & Business	0.24	0.22
Education Science	0.22	0.34
Other Social Sciences	0.18	0.25
Medicine & Paramedics	0.20	0.31
Bio-engineering	0.20	0.30
Languages	0.08	0.28
Cultural Studies	0.18	0.25
Total	0.19	0.28

Table 2.9: Profit changes resulting from unilateral program cuts (averages across institutions, in Euros)

	Current tuition revenues		Change in tuition revenue		Change in revenue from concentration index	
Study field	Colleges	Universities	Colleges	Universities	Colleges	Universities
Architecture	51,440	36,497	-40,916	-20,978	-29,318	7,385
Engineering	63,251	148,479	-32,127	-93,197	-9,585	-22,235
Science	n/a	83,564	n/a	-14,300	n/a	46,624
Economics & Business	152,231	103,980	-34,511	-52,456	7,003	-86,632
Education Science	104,185	153,169	-31,000	-46,373	-5,698	-2,702
Other Social Sciences	65,462	283,835	-46,700	-66,046	-19,978	-35,296
Medicine & Paramedics	33,807	84,144	-14,544	-18,187	25,823	29,763
Bio-engineering	20,252	93,676	-10,662	-32,316	41,517	-79,317
Languages	80,351	75,208	-74,406	-15,074	-44,938	16,293
Cultural Studies	60,703	98,238	-11,028	-16,029	25,421	15,665
Total	72,626	115,809	-28,797	-34,620	3,410	-12,265

In case an institution offers a study program of a given type on several campuses, the numbers indicate the (changes in) revenues at the campus level.

Table 2.10: Welfare changes resulting from unilateral program cuts (averages across institutions, in Euros)

	Change in consumer surplus		Variable cost saving		Gross welfare	
Study field	Colleges	Universities	Colleges	Universities	Colleges	Universities
Architecture	-139,465	-122,359	7,424	129,958	-132,040	7,599
Engineering	-116,347	-522,386	8,294	518,385	-108,053	-4,001
Science	n/a	-61,304	n/a	69,316	n/a	8,012
Economics and Business	-116,828	-223,150	-68,665	-58,677	-185,492	-281,827
Education Science	-106,110	-233,903	31,800	63,963	-74,310	-169,940
Other Social Sciences	-161,877	-285,889	4,229	-90,552	-157,648	-376,440
Medicine and Paramedics	-50,735	-87,441	13,300	141,175	-37,435	53,734
Bio-engineering	-39,502	-153,821	6,730	26,009	-32,771	-127,811
Languages	-244,516	-69,663	-79,543	-14,222	-324,058	-83,886
Cultural Studies	-38,176	-68,978	-19,554	-18,879	-57,730	-87,857
Total	-100,102	-162,677	-2,923	46,653	-103,025	-116,024

Table 2.11: Welfare changes resulting from joint program cuts (in Euros)

	Change in consumer surplus		Variable cost saving		Gross welfare	
Study field	Colleges	Universities	Colleges	Universities	Colleges	Universities
Architecture	-1,415,166	-368,366	78,561	392,328	-1,336,605	23,963
Engineering	-4,977,878	-1,603,136	399,535	1,619,947	-4,578,343	16,812
Science	n/a	-433,835	n/a	494,186	n/a	60,350
Economics & Business	-2,907,661	-1,585,569	-1,753,484	-422,909	-4,661,146	-2,008,478
Education Science	-2,867,354	-704,974	900,427	192,877	-1,966,927	-512,096
Other Social Sciences	-2,163,779	-1,737,184	57,619	-556,513	-2,106,160	-2,293,696
Medicine & Paramedics	-1,445,258	-527,753	387,231	855,289	-1,058,027	327,536
Bio-engineering	-678,502	-935,694	116,748	160,087	-561,754	-775,607
Languages	-1,254,113	-421,354	-415,025	-86,234	-1,669,138	-507,588
Cultural Studies	-425,174	-415,203	-219,649	-114,050	-644,823	-529,252
Total	-18,134,886	-8,733,067	-448,037	2,535,010	-18,582,923	-6,198,057

Table 2.12: Welfare incentive for the 225 study alternatives by type and study field

	Welfare effect			
Profit incentive	Negative	Unknown	Positive	Total
Negative	85 cases (desirable status quo)	2 cases	1 case (undesirable status quo)	88 cases
Unknown	58 options	0 cases	7 cases	65 cases
Positive	63 options (undesirable reform)	1 case	8 cases (desirable reform)	72 cases
Total	206 cases	3 cases	16 cases	225 cases

Chapter 3: Top Research Productivity and its Persistence

Abstract

The paper[65,66] contributes to the debate on cumulative advantage effects in academic research, by examining top performance in research productivity and its persistence over time, using a panel dataset comprising the publications of biomedical and exact scientists at the KU Leuven in the period 1992-2001. The data set allows taking into account factors like gender, age, cohort, rank, promotion, seniority, teaching load and access to research funding. About one quarter of the scientists in the sample achieve top performance at least once in the observation period, with six out of a hundred scientists being persistently top. Analyzing the selection and hazard to first and subsequent top performance, shows support for an accumulative process with rank, hierarchical position, access to funding and past performance as highly significant explanatory factors. Also gender is a consistent factor in explaining both top performance and its persistency.

3.1 Introduction

The use of publication- and citation counts as instruments for evaluation of individual scientists within research institutes as well as for funding decisions for research labs and universities as a whole is becoming more widespread. Moreover, the allocation of research funding is increasingly being driven by criteria of scientific

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65 This chapter is joint work with Reinhilde Veugelers.

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excellence, concentrating more funds in fewer hands. Yet, there are few academic studies on what drives top research productivity. A body of empirical research has recently emerged that attempts to pin down the determinants of scientific productivity, both at the level of the individual researcher and the more aggregate, institutional level. However, few studies have addressed the skewed distribution of research productivity, explaining top research productivity and its persistency over time. What makes someone a top researcher? Why do (some) top performers manage to sustain their high productivity level while others peak in scientific output only sporadically or never? Do exogenous factors, like gender and age explain top performance and its persistence over time? Or does the research system promote persistence of productivity differences by favoring/funding the better researchers?

This paper studies top research performance and its persistency over time, using a recent panel data set from the KU Leuven, comprising ten years of publication data 1992-2001. We first identify the selection of researchers into productivity categories (top, medium, low), using a clustering analysis and controlling for scientific discipline and time effects. This allows us to identify top researchers and persistent top researchers, viz. those who show up in the top productivity cluster in every period. We check whether top research performance displays persistency by constructing mobility matrices showing the moves to and from the top performance category between periods.

Next, we analyze the determinants of top research performance and its persistence in more detail. We employ a duration model to study the factors that influence the hazard for a researcher to achieve a first and subsequent top performance level, taking into account time-varying and invariant covariates and checking for the influence of past (top) performance. In particular, we address the following questions:

- What determines whether a researcher will ever achieve a first top performance, and what does the path towards this first peak in performance look like (gradual versus sudden)?

- Once a top performance level has been achieved for the first time, do the same determinants stay at the forefront to explain subsequent top performances?

- To what extent does a next top performance depend on previous top performance, controlling for individual heterogeneity?

Finally we check the robustness of our hazard analysis on the factors driving top performance and persistence in top performance using logit analysis.

The data set allows taking into account the standard factors in scientific productivity analysis, like gender, age, seniority, cohort, scientific discipline. In addition, the record of each researcher contains department affiliation, promotion, hierarchical position, awards of research funding, teaching load and administrative duties. The panel structure of our data set allows separating age and cohort effects, including fixed effects. In our search for driving forces, we are particularly interested in the "system" factors, that can create persistency of top performance, like rank, hierarchical position and funding.

The remainder of this paper is organized as follows. The next section presents a brief literature survey. Section 3.3 provides information on the data. In section 3.4 we identify top research productivity and its persistence, while in section 3.5 we analyze the characteristics determining the process towards top performance and its persistency. In section 3.6 we conclude and touch upon directions for further research.

3.2 Literature Survey

Most existing studies concentrate on the effects of individual determinants of academic productivity. The aspect of individual productivity that has received most attention is research productivity over the life cycle of the researcher. The earlier studies on US data (e.g. Bernier et al. (1975) and Cole (1979)), find a curvilinear relationship between age and both quality and quantity of scientific productivity.

A limitation of these earlier studies is their use of cross-sectional data, which does not allow to disentangle age from experience and cohort effects (Stephan, 1996). Levin and Stephan (1991), using longitudinal data of American scientists, find that life cycles effects are present in five of the six areas of physics and earth sciences studied, with publishing activity initially increasing and then declining somewhere in mid-career.

Gender differences in scientific productivity are another line of attention. Several studies have found that female scientists publish at lower rates than male scientists. Using a sample of American biochemists, Long (1993) finds that sex differences in the number of publications and citations are bigger during the first decade of the career but are reversed later. He attributes the lower productivity of females to their overrepresentation among non-publishers and their under representation among the extremely productive.

In a more recent study of French condensed matter physicists, Mairesse and Turner (2002) analyze the impact of age, gender and education on research productivity. They confirm a quadratic relation between the age of the scientists and the number of publications. They also find significant positive effects for males and graduates from the French Grande Ecoles. Their results also indicate a positive time trend, suggesting that there has been a wider and faster access to publication.

In view of the significance of team effort in science, it is important to assess collective effects on individual productivity as also Stephan (1996) argues. Early research in the USA found researchers at prestigious departments to be more productive and cited than their colleagues in lower-ranked universities (Cole and Cole, 1973). Also Turner and Mairesse (2004) provide evidence that the quality of other researchers belonging to the laboratory is a crucial variable for explaining individual productivity.

To summarize, existing studies assessing individual research productivity have indicated the importance of individual characteristics like age, cohort and gender as well as collective characteristics of the laboratory or department to which the researcher belongs, whilst controlling for scientific discipline idiosyncrasies.

Most of the studies to date aim at explaining average productivity profiles, ignoring the often skewed distribution of research productivity. This skewed distribution was first evidenced by Lotka (1926), with many researchers non-active and a few researchers accounting for the bulk of the publications. Furthermore, existing studies analyze publications in a cross section or a short period of time, not allowing to properly account for time persistence of productivity patterns. This issue of persistence of research productivity profiles remains largely unexplored in the literature.

Why would we expect research productivity to be skewed and this skewedness to persist? First, talent is important in determining research productivity. Top research may require a "magic gland" (Stephan and Levin, 1992), a special edge, an innate ability. Those pre-determined differences are unevenly spread in the population. Those who have it, are always productive, those without, never see their careers take off and flourish. Hence, a differential distribution of talent within the scientific community will lead to research productivity differences which persist over time. Of course, luck also enters the picture, especially when explaining the occurrence of "hits" following a scientific discovery. Although luck enters in a variety of forms and is often accompanied by serendipity, it nevertheless predicts a more random and non-persistent top research productivity for the individual researcher.

But next to talent and luck, effort is a particularly important factor explaining scientific output. When researchers decide on the level of effort to exert, they trade costs and benefits. Costs of effort will be lower for the more talented researchers, resulting in an interaction between talent and effort driving (persistency of) top performance. Furthermore, in line with research on firm growth (e.g. Jovanovic (1982), Pakes and Ericson (1998)), one can argue that the effect of talent is not a fixed effect over time, particularly when interacted with effort in a learning perspective. Initially researchers may be uncertain about their talent when they enter the field, but gradually discover their capabilities from being active in the field (as in the passive learning models of e.g. Jovanovic (1982)), and/or from making efficiency enhancing investment (as in the active learning models of e.g. Pakes and

Ericson (1998)). Both directions predict that younger and "smaller" researchers will have a higher potential for learning and hence variance in performance over time, while older researchers will have a higher persistence in performance as they are more confident about their talents. Once a researcher learns she is good at it, she will be more motivated to put effort into the process.

Several benefits may motivate scientists to exert effort, as argued by Stephan & Levin (1992), Dasgupta & David (1994): monetary rewards, recognition and the "puzzle" joy. These motivational forces may explain persistency in research productivity through a process of accumulative advantage where motivation to exert effort depends on past performance. The Matthew effect described by Merton (1968) states that the recognition and monetary value awarded to a scientist's accomplishments depends on his status in the scientific community. Highly productive researchers maintain or increase their productivity because they receive recognition and resources, while those scientists who do not, become less productive. Successful scientists get their work more easily published, get easier citations, research funding, quicker tenure and promotion, higher wages, jobs in more prestigious institutions, better infrastructure, better and more PhD and post-doc students... Early evidence for the Matthew Effect using citation data on US physicists was found by Cole (1970) who found it may result in temporarily ignoring scientific discoveries. In sum, being more recognized and having access to more and better resources, more productive researchers will devote more effort to scientific output, leading to persistency in research performance. They may even escape the typically observed non-linear age profile, being less likely to relocate efforts at mid-life. Zuckerman & Merton (1971) argue that this tenacity occurs not only because the successful have accumulated advantage and have become addicted to recognition, but also because they see this as a process to validate the judgments of the scientific community that their capacities have been correctly assessed.

There is a lot of anecdotal empirical evidence on accumulative advantage (see e.g. Stephan & Levin (1992)), but little recent systematic empirical analysis. In one of the earliest studies, Cole & Cole (1967) investigate the nature of the scientific reward system using a sample 120 US physicists. They find a stronger link between quality of research and recognition than between research quantity and recognition. They conclude that the reward system primarily induces the more creative scientists to be more productive while it diverts the energy of the less creative scientists to other activities, leading to a high correlation between quantity and quality of research, especially at top departments. Allison and Stewart (1974) present an empirical analysis on productivity dynamics using a cross-section of chemists, physicists, and mathematicians in the US, and find that the highly skewed distributions of productivity among researchers can be explained by a process of accumulative advantage. This inequality becomes increasingly unequal as career age increases. In an extension of this study, Allison et al. (1982) examine cohorts of biochemists and chemists, and they confirm that increasing inequality is observed for counts of publications but not for counts of citations to all previous publications.

3.3 The Data

The data set we use to assess top research productivity and its persistency is a unique panel of 1,036 scientists within the fields of biomedical and exact sciences, in the period 1992-2001, employed at the KU Leuven, the largest and oldest university in Belgium. In terms of research, the KU Leuven has the ambition to establish a top position in "poles of excellence", and have a good performance in the other areas[67]. To this end it allocates research funding to research proposals on the basis of (international) peer review of excellence in research. Recruitment and promotion decisions also carry a strong research quality requirement. In addition, research output (quantity and quality) of its entire academic staff is regularly monitored.

We pooled different sources of data sets, combining information from the personnel administration of the KU Leuven with bibliometric data[68]. The dataset contains the following information:

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67 For background on institutional features of the KU Leuven, see appendix 2 of this chapter .

68 Appendix 1 of this chapter contains details on how the database was constructed.

- Scientific output (per researcher per year[69]) i.e. publications in ISI journals classified by scientific discipline[70,71];
- Individual and career-related variables (per researcher per year) i.e. gender, age, cohort (year of entry at KU Leuven), career age, rank (assistant professor, associate professor, professor and full professor), seniority in rank, full-time versus part time position;
- Organizational membership at group- (exact versus biomedical sciences), faculty- (e.g. medicine) and department (e.g. microbiology and immunology) level;
- Other information relevant for examining scientific performance, viz. *actual* teaching load, other administrative duties within KU Leuven, being head of a research unit, and involvement as a promoter or co-promoter of research projects awarded on a competitive basis. Two major types of funding can be identified: the larger Type I (excellence) and the smaller Type II funding. See Appendix 2 in this chapter for a description of the KUL research strategy and the type of funding it awards.

Most researchers in the sample were not employed for the full 10 years: some of them retired or left the university before 2001, others joined after 1992. These

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69 "Year" always refers to a "database year" i.e. the year in which the publication was taken up in the ISI records.

70 A key characteristic of the dataset is that it allows controlling for scientific discipline-specific effects: the KU Leuven Centre for R&D Statistics classified every journal covered by the SCI into one or more twelve high-level disciplines, all within the field of exact or biomedical sciences. This allowed us to assign to each scientist the disciplines in which she published a paper in that year. About 21% of all researchers could not be assigned to a main discipline because they did not publish in the period 1992-2001. For all others, we determined a 'main discipline' for each researcher, which is defined as the discipline, taken from the twelve high-level disciplines, in which the researcher has the most publications in the period 1992-2001. For 58 researchers there was a tie i.e. they published an equal amount of papers in at least two disciplines. For them we randomly assigned a main discipline from the tie disciplines. Table 3.2 shows the final distribution of the researchers in the sample over the disciplines.

71 There is also scientific output that does not fall under the scope of the Science Citation Index of the ISI. For instance, the ISI database does not include proceedings, which in some disciplines, like engineering, are an important publication outlet.

entries and exits yield an unbalanced panel and allow examining cohort effects. The data set holds on average 778 researchers per year in an unbalanced panel[72].

Table 3.1 and table 3.2 present the distribution of scientists over the respective faculties and disciplines within the Biomedical and Exact Science groups of the KU Leuven. Both groups, each comprising three faculties, are comparable in size. Within the group of Exact Sciences, the faculty of Science (192 professors) and the one of Engineering (214) are the largest. In the group of Biomedical Sciences, the faculty of Medicine (460 professors) clearly dominates in terms of size. The vast majority of all researchers in the panel (94%) is professor and hence combines research and teaching activities. Considering both scientific discipline and organizational membership allows disentangling scientific discipline-specific influences from organizational and managerial effects.

The first column in table 3.3 reports year averages for the individual and career-related characteristics of the researchers in the whole sample. About 89% of them are male with an average age of 47.7 years. On average, the youngest age cohort (professors less than 40 years old) constitutes one quarter of all researchers. 38% of the researchers entered as a professor in or after 1992. With respect to tenure (not shown in the table), 76% of the researchers in the sample have tenure in every year that we observe them, 15% never have tenure and 9% switch from a temporary contract to a fixed appointment. We distinguish between four main ranks, with rank 1 the entry level ("assistant professor") and rank 4 the highest possible rank ("full professor"). One quarter of researchers have the most junior rank, whilst about the same quantity have reached the top of the career ladder. 80% of the scientists have a full-time position at the university either in one single contract or in a combination of several positions. The average teaching load for a professor amounts to 4.18 year-hours[73] and increases monotonously with rank. On average 9% of the sample is involved in a type I project as a promoter or co-

[72] Given our focus on persistence, we restricted the dataset to researchers whom we observe for at least 2 periods. For 97 researchers there was only one observation in the dataset; these were dropped, leaving 1,036 researchers.

[73] A year-hour gives the average weekly teaching load in an academic year. One year-hour corresponds to 30 teaching hours.

promoter, while 11% (co-)promotes a type II project (see Appendix 2 in this chapter for a description of the nature of these research projects).

As shown in the first column of table 3.6, on average a researcher publishes 3.3 articles per year[74]. But this average has a high standard deviation (5.1). The propensity to publish varies greatly among disciplines: the average number of publications per year ranges from 1.8 for mathematics to 7.5 for biosciences[75] (see table 3.4). All this reflects the importance of scientific discipline specific effects when examining research productivity. In terms of output quality as measured by a 3-year forward citation window, the KU Leuven researchers score above the world average in six of the twelve disciplines. Finally, publication activity has increased over time in all disciplines as shown in figure 3.1, indicating the importance of correcting for time-effects.

3.4 Descriptive Analysis

3.4.1 Performance Profiles: Identifying Top Performance

In order to identify top performance we carried out a clustering of the researchers' publication records into three "productivity categories" (top, medium, low). We focus our output analysis on the number of publications only, see infra. In particular, we compared for each year the scientist's performance within each of the twelve disciplines with colleagues who are active in that discipline, using k-means clustering. This allows to correct for the discipline-specific publication patterns documented above, as well as for time trends. Every researcher is judged not only by his or her main discipline but, given the degree of multidisciplinarity, for each of the twelve disciplines. Subsequently, we aggregate across disciplines. The researcher is considered as "top" in a particular year if she belongs to the "top cluster"

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[74] A publication gets on average 3 citations and has an impact measure of 3.2. A scientist collaborates on a paper on average with 4.7 co-authors. She acts as as (co-)promoter of 0.3 PhD's per year.

[75] This high degree of heterogeneity across scientific disciplines also holds for other output measures such as citations, impact factors and co-authorship, as shown in Table 3.4.

in at least one of the twelve disciplines[76]. Similarly, she is classified as "low" in a particular year if she belongs to the "low cluster" for each discipline. Because the publication process not necessarily adheres to a year-by-year logic, the yearly performance measures are used to construct a performance indicator based on a two-year moving window[77]. This avoids that we label generally very productive researchers as non-persistent in top-level output in case they happen to face a year with many projects in the pipeline but with relatively few actual publications.

On average 16% of observations are classified as a top performance whereas 32% vs 52% end up in the medium respectively the low productivity categories. This top 16% of observations accounts for 42.95% of all publications in the sample, while the 52% observations representing low performance jointly supply 7.11% of all output, confirming the skewness in the distribution of publications.

3.4.2 Establishing persistence: Once Top, Always Top?

In order to establish whether persistence in top performance exists, we look at the mobility of researchers between the productivity clusters. Scientists who "get trapped" in the low research productivity category may spend their time on other things such as teaching or internal management duties, may not have the intrinsic ability for doing research, or may face a system geared at stimulating the past performers. The latter interpretation attributes persistent low scientific output to a cumulative advantage mechanism that disadvantages researchers with a low initial output. The same cumulative advantage will generate persistency at the top.

To capture researchers' mobility across productivity clusters, we constructed a series of transition matrices. Table 3.5 shows the mobility matrix for the transition of 1992/1993 to 1993/1994, relating the three productivity clusters (low / medium

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[76] In total 12x3x10 clusters are created (12 disciplines, 10 years). Comparing the mean number of publications for the clusters within a discipline using a ranksum test, in 10 cases the null hypothesis of identical means cannot be rejected.

[77] This entails the loss of one observation per researcher. The reported results are not sensitive to a yearly versus two-year moving window. For some types of research projects with long set-up times, two years may not be enough to cover temporary output gaps. Longer time frames were not used however, due to the limited time dimension of the panel (10 years). Future updates of the dataset resulting in longer panels will offer more freedom in this respect.

/ top) of 1992/1993 to those of the subsequent 2-year interval. If previous output were irrelevant for explaining current performance, we would see the same distribution of researchers within a subgroup as in the whole sample. The data shows that previous performance is a strong indicator of future performance: 76.1% of the high performers in 1992/1993 repeat their high output in the next year, a higher than expected percentage (17.4%)[78]. We may conclude that researchers tend to be rather immobile in their scientific output. All this evidence goes against a "luck" theory for explaining top performance, favoring more the intrinsic qualities, the gradual accumulation and Matthew effect as explanatory factors.

Having established the phenomenon of persistency in top performance, a next step is to identify the persistent top performers. We measure the persistence of each researcher by counting the number of years in a cluster relative to the years of her employment. In particular, we classify a researcher as persistent top if she belongs to the top performance category in every two-year window in 1992-2001 during the period in which she was employed by the university. Analogously, the non-persistent top-group contains those who belong to the top category at least once but not in every two-year window of their employment. The scientists that do publish but never make it to the top group are labeled average whilst the remaining researchers are inactive. This yields an exhaustive classification of researchers into 4 "persistence categories", as shown in table 3.6.

Only 61 researchers (about 6% of the sample[79]) are part of the top productivity category for every two-year window of their employment in 1992-2001. These 6% persistent top researchers account for 24% of total publications in the sample, confirming again the very skewed productivity distribution. About 21% of the sample belong to the top category at least once but not persistently. Slightly more than

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[78] The 'low'-category is the most immobile category with a lower than expected probability to switch to the middle category and almost no one leaping to the high category. The Pearson Chi^2-statistic (635.14) confirms that performance levels across these two periods are not independent. Similar results are obtained for transition matrices covering the other two-year intervals.

[79] If we had used a one-year window to assess persistence, we would have ended with only 20 individuals, or 2% of the sample, in the persistent top category.

half of all researchers (52%) may be classified as "average" whilst about 21% of the sample have a blank publication record throughout the observed periods[80].

Pairwise comparisons using the Wilcoxon ranksum test show that the average number of publications differs significantly for the persistence categories, indicating that we can meaningfully distinguish between them. But the different categories do not only differ significantly in terms of number of publications, but also with respect to the quality of publications. Although we focus our output dimension for identifying top performers on quantity of publications only, we find, in line with other studies, that quantity and quality of publications are correlated. All research output measures for quality (citations, impact measures) decline monotonously when moving from the persistent top researchers to the inactive category. Nevertheless, the decline is less outspoken with respect to quality measures than with respect to number of publications.

A concern with respect to the classification procedure is that the people we identify as (persistent or non-persistent) top researchers may not be such eminent scientists if we compare them to the overall distribution i.e. including non-KU Leuven researchers. For instance, the best researchers may leave the institution to accept a position at a top university abroad. Outbound mobility of top researchers turns out to be very limited however: only 2 of the 61 persistent top researchers leave the university before the age of 40, and none of the non-persistent top researchers[81]. As an additional check, Table 3.7 shows that the 61 KU Leuven researchers we identify as persistent top are also excellent scientists when comparing them to the overall distribution of scientists. Specifically, the persistent top group greatly outperforms the world average research quality as measured by the average number of citations per publication. In addition, 8 out of the 61 persistent top researchers appear in the ISI Highly Cited database (ISI, 2007). Given the selectivity

80 Inspection of the data reveals that we can attribute this apparent 'inactivity' (at least partially) to the involvement of staff as practitioners in their field of expertise. In other words, some staff members may have a full-time position at the university but are nevertheless not expected to carry out research. In particular, there are four departments where more than one third of full-time staff doesn't show up in the ISI publication records. It concerns the departments of architecture, public health (where general physicians are trained), sports & motion sciences and kinesiology.

81 Only 6 out of the 279 top researchers leave the university before the age of 50, viz. 4 persistent toppers and 2 non-persistent toppers.

of this database[82], we take this as another indication that we do not rank researchers on purely internal benchmarks and thus rightfully measure scientific excellence.

Splitting the individual and career-related variables by persistence category (see table 3.3), yields some initial hints with respect to different researcher profiles. For example, we see that women are underrepresented in the top performance categories but overrepresented in the persistent non-active and in the average category, as in Turner & Mairesse (2003). Furthermore, we do not find the older age cohorts to be underrepresented among the most productive researchers. This confirms that the most productive researchers do not display the life cycle effect found in other studies. This is not the case for the unproductive researchers where the age categories above 50 and especially above 60 are overrepresented, pointing at segregation on the basis of age at the bottom of the productivity distribution.

Related to the age results are the ones with respect to rank. There is strong overrepresentation of full professors among the persistent top. In addition, as shown by average rank seniority, top researchers tend to spend less time through the three ranks preceding full professor than average and inactive researchers, while inactive researchers tend to stay longer in the less-than-full-professor rank. All this suggests that the promotion procedures in place at the KU Leuven seem to select the more prolific faculty.

The table reveals that it is important to correct for the type of contract: while almost all persistent toppers are full-time, less than half of the researchers who don't publish have a full-time position at the university. Also, inactive and average productive scientists are more likely to have entered professorship recently i.e. after 1992. Recent hires might suffer a disadvantage since they are less likely to have made it already to the top cluster given their shorter employment history in a cumulative process.

As far as the research-teaching trade-off is concerned, persistent and non-persistent top researchers tend to have a similar teaching load than the average re-

[82] The ISI Highly Cited database includes the publication and achievement records of just 250 preeminent researchers in 21 categories including life sciences, medicine, physical sciences, engineering, and social sciences.

searchers. The results on research funding shows marked differences for persistent toppers. 22% of persistent top researchers are involved in type I projects compared to 20% for the non-persistent top researchers (with researchers in the latter category acting more often as co-promoters than as promoters). The average category is seldom involved in these research projects. Type II funding shows a comparable pattern with the more productive categories participating more frequently although the "less exclusive" character of type II funding is reflected by the average category taking part more in these than in type I projects (11% versus 7%).

3.5 Multivariate Analysis of Top Research Performance and its Persistence

In this section, we take a multivariate look at the process to top performance and its persistence. We use various approaches. In section 3.5.1 we use a duration analysis to study the determinants of top research productivity, both first and subsequent top performance. To check robustness of results, we present in section 3.5.2 a logistic model for top performance and persistence in top performance.

3.5.1 Hazard Analysis of First and Repeated Top

In this section, we use a duration model approach to determine which independent variables are significantly correlated with the "survival time" in the non-top research productivity category. This allows discussing which characteristics influence the probability of becoming a top researcher at some point in time.

The Cox proportional hazards model

We use the Cox proportional hazards model (1972) where the event of interest is top research performance in a given time period[83]. The model specifies the hazard to be top for the j-th individual as the product of a baseline hazard $h_0(t)$, i.e. the

[83] More specifically, we use the two-year intervals discussed in section 3.4.1.

hazard when all covariates are equal to zero, and the exponential function of the parameters β_x and regressors x_j:

$$h(t|x_j) = h_0(t)\exp(x_j\beta_x)$$

The baseline hazard is left unspecified, meaning that the model makes no assumptions about the shape of the hazard over time. We opt for this approach since theory does not provide us with a reasonable assumption about the shape of the hazard. The cost of this semi-parametric approach is a loss in efficiency.

We use two types of hazard models. The first one analyses the hazard to first top performance. In this case, once a top performance is reached, the researcher is removed from the sample. Hence, for this analysis, the sample consists of all observations prior to (and including) a researcher's first top performance. This allows concentrating on the process towards first top performance, but ignores subsequent observations on performance. Nevertheless, given the skewed distribution of top performance in the sample, the overwhelming majority of observations are maintained in this analysis.

Using all information in the data, we also estimate a repeated events model, where we model not only the hazard to first top performance, but to all top performances. We impose a sequential ordering of events: a researcher can only be "at risk" for her k-th top performance if she achieved $k-1$ top performances in the past. A key element in our approach is that we allow the risk process underlying top performance to change with the occurrence of previous top performances. The main model estimates a common baseline hazard across event ranks as in the Andersen-Gill counting process model[84] (1982) but with the inclusion of a previous events counter which allows the hazard to differ proportionally between top performances[85].

84 The counting process definition of the duration variable uses the time of the $(k-1)$th top performance as the starting time for each risk interval. This set-up is preferable when the substantive interest is in the evolution of the risk to be top as a function of time since the onset of risk.

85 As a robustness check we also estimate the model with a restricted or 'stratified' risk set i.e. with different baseline hazards per top performance, commonly known as the Prentice-Williams-Peterson model (1981). This latter model may be estimated using either a counting process or gap time formulation of time, allowing us to check which view of the risk process fits the data best. The

Given that we work with multiple failure-time data, the failure times pertaining to a single researcher will be correlated, violating the independence of failure times assumption required in traditional survival analysis. This problem is avoided in the first top performance analysis, but taking into account repeated events introduces dependence between failure times pertaining to a single researcher. We account for this by adjusting the covariance matrix of the estimators. In general however, this approach does not fully address the problem since an individual's top performances may be correlated due to a characteristic not being measured, such as ability, instead of being brought about by an accumulative advantage process. Therefore, as an additional robustness check we estimate a model where a latent random effect, or "frailty", enters multiplicatively on the hazard function: $h_{ij}(t) = h_0(t)\alpha_i \exp(x_{ij}\beta)$. The frailties α_i are unobservable and are assumed to follow a gamma distribution with mean one and variance to be estimated from the data. If the variance differs significantly from zero, then the null hypothesis of no unobserved heterogeneity cannot be maintained.

Censoring and truncation

We define the starting time for the duration variable as the moment when the individual enters as assistant professor at KU Leuven. Our observation window ranges from 1992 to 2001. This implies that the majority of researchers in the sample are "at risk" prior to 1992 and that their performance data are left censored to the extent that we do not know whether or how many times these scientists achieved top performance i.e. the censoring value is not known. Analogously, 86% of researchers is last observed at censoring time 2001 but continues to be at risk and we are ignorant of their performance beyond this point. While this right censoring is not likely to affect our results, the left censoring is a more important issue.

We will consider all individuals who became a member of the faculty prior to 1992 as cases of "late entry" in the risk set i.e. we treat these individuals as not ob-

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gap time approach 'resets the clock' to zero after each top performance. This definition of time is preferable when the risk process varies as a function of time since the occurrence of the previous top performance.

servationally at risk of being top, ignoring top performance before 1992. We use the same approach for the right-censored observations, thereby making the assumption that durations are independent of observed entry and exit times. Stated differently, we assume that the censoring is non-informative (Cox and Oakes, 1994). We nevertheless include an entry cohort dummy for those individuals having entered before 1992. We will also perform the analysis on the sample excluding the faculty which have entered before 1992.

Finally, the dataset contains observations that are terminated before censoring time. It concerns individuals who left the university or who retired before 2001 (14% of researchers). The precise reason of termination may be important for the same non-informative censoring requirement as above, a condition which is violated if termination is in some way related to survival time. This could be the case if individuals tend to self-select out of the university once they gain experience about their capacity to deliver as a researcher[86].

Variables

The dependent variable is the hazard to enter the category of top performance, either as a first or repeated event. The categorization of top performance, as defined in section 3.4.1, is time and discipline specific. This takes care of discipline and time specific effects that may drive the definition of what constitutes a top performance in terms of number of publications required for such top performance.

Which independent variables do we consider to influence this hazard to top performance? The existing studies assessing individual research productivity reviewed in section 3.2 have indicated the importance of individual characteristics like age, cohort and gender. Also collective characteristics of the laboratory or department to which the researcher belongs have been indicated as important. In line

[86] In support of the argument that the data displays non-informative random censoring, we see that the majority of terminations happens at relatively advanced age (more than 60% of leaving scientists is older than sixty, on a pre-retirement scheme). Furthermore, for the terminations before retirement time it is likely that these people leave because they, for example, got a good outside offer and not because they consider themselves inadequate researchers: there are no significant differences in research performance between the researchers leaving the university before the age of 50 and those of comparable age, rank and discipline, staying. Moreover, the university has not yet a history of firing people for low research performance.

with the existing literature we include the same characteristics, this time to check whether they play a role in explaining the hazard to (first and repeated) top research performance.

Following earlier studies, we include gender to check whether females are less likely to deliver (repeated) top performance. Second, we include age and age squared, with the squared term to check for non-linear age effects, as in previous analyses on research productivity. We expect age to be beneficial for generating top performance, given that it takes time and experience to build an advantage. Furthermore, if there is accumulative advantage, we expect no concavity for age in the repeated top performance analysis, with top performers being able to beat the age decline. To disentangle age from cohort effects, we also include dummies for entry into the sample. The most important cohort effect seems to be a marked increase in hiring by the KU Leuven in 1992[87]. There were no other cohort shocks that could be identified[88]. The dummy for entry after 1992 also allows at the same time to correct for left censoring.

All existing studies indicate the importance of controlling for scientific discipline idiosyncrasies. Although our top performance classification is already discipline and time specific, we nevertheless include scientific discipline dummies to check whether discipline-specific aspects remain important in the process towards top performance.

Beyond the traditionally considered variables like age, gender, cohort and scientific discipline, the KU Leuven personnel data set also allows to include a number of other determining variables. A first set of variables reflects the influence of the personnel strategy of the university to reward and provide incentives to its researchers: rank and seniority in rank[89]. With respect to rank, we would expect, all else equal, that those researchers up for promotion will have a higher motivation to provide inputs into the research process. Once promotion is acquired there is less motivation for delivering star performance. In lower ranks, researchers should

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87 This peak in hiring corresponds mainly to a growing number of retiring faculty that needed to be replaced.

88 When including a full set of cohort dummies, no significant effects could be detected.

89 Rank correlates with tenure: all researchers of rank 2 and above always have tenure.

have more incentives to put in effort to get promotion. On the other hand, the higher ranks also have more incentives to put in effort to "prove their rank". Since past research performance is taken into account when hiring and promoting, it is likely that top performance will increase the probability of getting a higher rank. To take this endogeneity (at least partly) into account, we include the rank variables with one period lagged relative to top performance. The variable seniority in rank should capture increasing pressure to provide effort, the longer a researcher is in his current rank (since the more likely she is to be up for promotion). But again we might expect a non-linearity: once a researcher is far beyond the expected seniority (typically two years), this might reflect a structurally reduced probability to get promotion. Also, the more senior, the higher is the wage and thus the smaller is the marginal benefit from increasing wage with rank. Especially in the end rank (full professor) seniority in rank looses its specific function and will correlate with age.

Beyond the seniority in rank, we also include seniority as professor (frequently referred to as career age). This variable might be important beyond the seniority in rank, since wages received by professors in Belgium are not only determined by rank, but also, and strongly, by seniority as professor.

We also include the organizational unit to which the researcher belongs at the KU Leuven. This allows capturing the influence of organizational structure and strategy to promote and provide incentives for research, to the extent that these units are responsible for developing a good research environment. It also allows correcting for the impact of spillovers from the quality or prestige of the group to which the researcher belongs. We include "faculty" dummies, since this is the most authoritative organization level at KU Leuven in terms of recruitment and promotion decisions. But we also perform analyses with "department" dummies.

Also important is to correct for fulltime or part time appointment at the universities, since part time appointments, in our sample mostly occurring at the engineering faculty, are typically for people from industry who are hired and evaluated on teaching rather than research.

The inclusion of actual teaching load should be able to correct for the lost opportunity time for research when having to teach students. Hence, we expect a negative effect on the hazard for top performance.

We also have information on whether a researcher heads a research unit. A head of a unit has access to resources for research (infrastructure and researchers), which allows him to be more associated with research output in the form of publications in his own name or from his team, as last author. Given that top performers are more likely to become heads of unit, there is an issue of endogeneity, so we lag this variable by one period.

Finally, (co-)promotership of research projects implies additional resources to do research and therefore is expected to contribute positively to performance. Especially the Type I projects involve serious amounts of research funding. Since research performance is typically taken up as a criterion to judge research proposals, we lag this variable by one period.

Results

a) First top performance

We start with discussing the results from the Cox models on first top performance only, reported in table 3.8. Estimates are presented in terms of their effect on the odds to be a top performer: a coefficient smaller (larger) than one, reflects a negative (positive) effect.

Being male almost doubles the odds of displaying first top performance (hazard multiplied by 1.86, see first model in Table 3.8). Rank is highly significant and the size of the coefficients indicates that lower ranks have a significantly lower hazard for first top performance as compared to rank 4 (full professor). This may be picking up the accumulative advantage effect that higher ranked professors get more resources, have more incentives to put in effort and have more experience, all of which increase their probability of realizing a top performance. On top op the rank effect, being a head of unit also considerably and significantly increases the hazard of first top performance (by a factor of 1.52). With heads of unit having available the research resources in their unit, they are more likely to be prolific, again supporting the accumulative advantage hypothesis. Once corrected for rank, age has a small and non-significant effect on the hazard and there is no sign of non-linearity in the age effect. Also seniority as a professor and seniority in rank have no significant effect[90]. Convincing evidence for a substitutive effect between research and teaching cannot be found as the teaching load coefficient, although negative, is small and only marginally significant. The correction for entry in or after 1992 shows a significantly higher hazard of first top for late entrants, suggesting that the researchers hired before 1992 are not at higher risk for top performance, on the contrary[91]. Even if we correct for the main discipline of the researcher in the model[92], the membership of the different faculties[93] matters for agriculture, medicine and pharmacy. Looking at the more detailed department membership (estimates not reported) reveals that organizational differences also continue to play a role within faculties. Additional research funding under the form of the type I projects, i.e. large "excellence funding", contributes significantly to the hazard of becoming top (hazard multiplied by 1.77), as expected. The smaller type II research grants do not make a significant difference for attaining top performance.

When we split the analysis by group (biomedical, engineering and sciences; results not shown) the importance of rank holds for the biomedical and science groups but looses its significance for engineering. The gender effect is driven by the biomedical observations as well as the impact of heading a research unit, while the engineering and, to a lesser extent, the science faculties show a significant and negative teaching effect (insignificant for the biomedical group). The positive impact of type I funding comes out significantly for the engineering and science faculties.

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[90] Dropping the seniority variables from the analysis does not improve the significance of the age coefficients.

[91] A robustness check including only fulltimers confirms the results, except for the dummy controlling for entry in/after 1992 which looses significance. Also for the subsample with entrants after 1992, the direction and magnitude of most effects are maintained, but the significance for many parameters disappears due to a limited number of observations.

[92] All discipline dummies are relative to the 'agriculture and environment' category. The multidisciplinary category was dropped from the regression (10 researchers).

[93] The faculty of physical education and kinesiology serves as the reference category.

Finally, to examine whether the *path to first top performance* is a gradual process requiring a steady build-up of publications rather than being characterized by a sudden burst in publication output, we include a specification that models the hazard of first top performance as a function of previous research performance (see second model in Table 3.8). In particular, we include a dummy which takes the value of one when the researcher belonged to the middle performance category in the previous period, the base category being the low performance category. This coefficient turns out to be highly significant and suggests a large effect: researchers in the middle performance category are about six times more likely to reach their first top performance in the next period, as compared to researchers in the low performance category, all else equal. This result strongly supports the gradual build-up of top performance, as was also found in the mobility matrices reported in section 3.4.2. An additional check shows that this effect holds for both male and female researchers (not reported). Women are less likely to jump from the low to the top productivity category, but the difference is not significant. Conclusions with respect to the other coefficients remain largely unchanged relative to the first specification[94].

b) Repeated top performance

Table 3.9 again looks at the hazard to be a top performer, but this time includes all top performances using a repeated events model. This is a further step in assessing the "repeatability" of top performance. Again, when we compare these results with the models for first top performance, we can single out whether the risk process underlying first versus subsequent top performance is different[95]. But in addition and most interestingly, the repeated events model has the advantage that it allows more explicitly analyzing dependence on prior top performance and the role of individual heterogeneity[96].

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94 An exception is the gender effect which looses significance. Also, the type I funding dummy looses significance while type II funding shows up with a negative effect. We attribute this to correlation between these variables and the medium performance lag.

95 Given that most of the observations in our sample (79%) pertain to first top performance, it will be difficult to find strong differences.

96 These findings are confirmed when estimating the stratified Cox model with separate baseline

The results in terms of which characteristics are significant are very similar to the results for first top performance (see first specification in table 3.9), such as the gender effect, which remains important and very significant[97]. The head-of-unit result is less strong in the repeated events analysis. The correction for fulltime position becomes more important once we take into account subsequent top performances. Teaching load has a small but significant negative impact, suggesting that teaching load becomes more a constraint for repeated top performance, although the effect is not robust in later regressions (see infra). The rank effect remains highly significant with all ranks below the most senior rank less likely to perform top. Both type I and type II funding have a positive effect on showing top performance, but these results are not robust in later regressions (see infra).

To further examine the persistence in research performance, we include in the repeated events analysis the number of previous top performances (the second model in table 3.9). If top performance is an accumulative process, we expect this variable to significantly affect the hazard for repeated top performance, contributing to the persistence in top performance. Indeed the results indicate a significant and substantial higher hazard for next top performance, the more previous top performances a researcher has acquired (52% increase in the hazard to be top). Note that the other parameters are little affected by the inclusion of the variable, with the exception of the control dummy for the most recent entry cohort that becomes significant. The small and positive career age effect becomes significant at the 5% level. Including the number of previous top performances takes away the effect of research funding, which is presumably due to correlation between these variables.

In the third specification we test to which extent there is a gradual accumulation of top performance experience, by allowing a different effect of first, sec-

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hazards per event rank, as explained in section 1. With respect to the appropriate view on the risk process, we compared the estimates of the stratified Cox model using both a gap time and a counting process formulation of time. The counting process formulation fits the data best. This implies that the baseline hazard to be top is a function of the total time path since entry as a professor, rather than being determined by the time since last top performance only.

97 An important finding with respect to the gender effect is that the coefficient looses significance in a model where we look at second or higher order top performance, conditional on first top performance (not reported). This indicates that the gender differential relates to achieving top performance for the first time, after which its importance disappears.

ond, third, etc. top performance on the next top performance. Although initially not monotonously increasing, the coefficients indicate an upward trend, suggesting that the more previous top performances the researcher has acquired, the higher the hazard for a next top performance, confirming the accumulative nature of the process towards top performance.

As discussed in section 1, if there exists within-individual correlation, the model above is misspecified. Table 3.10 reports the results using a Cox shared frailty model[98], with the first specification showing the repeated events model with the previous events counter from the previous paragraph, for reference. The frailty model allows checking whether the accumulative advantage effect coming out of the model is robust when controlling for unobserved heterogeneity, for instance the individual's talent. The main parameter of interest is the variance of the frailty terms (theta). The likelihood ratio test for the second model in the table shows that we can reject the hypothesis of no individual heterogeneity. When correcting for individual fixed effects in this way, all supra reported results remain. More particularly, the effect of previous top performance, although smaller than before (1.29 versus 1.52 as shown in the table), remains sizeable and very significant. All this suggests that on top of a accumulated advantage story, individual heterogeneity (talent) remains an important factor in determining first and subsequent top performance.

The third model in the table reveals that men and women show a different sensitivity to past top performance with respect to the odds of repeating top performance. For a female researcher, each top performance more than doubles the odds to be top again (2.33). For male researchers, the effect of a previous top performance is only about half compared to women (0.56). Note that we control for individual heterogeneity, so the different impact of past top performance for men and women cannot be attributed to a systematic difference in, say, unobserved ability. The estimates would suggest that female scientists are more sensitive to the cumulative advantage effect than men. Intuitively, this may be explained as top

[98] The frailty is shared by all observations pertaining to a single individual and hence captures within-individual correlation.

performance having an even stronger status effect if achieved by researchers operating in an underdog position, which arguably holds for women in science.

Finally, when plotting the baseline hazard[99] (see figure 3.2), visualizing the shape of the residual risk over time after controlling for all the observable factors, we see that the more time elapses since entry in professorship the less likely it is the researcher will ever reach top performance.

In sum, the duration models yield interesting findings with respect to first and subsequent top performance. In all the models used, the scientific discipline of researchers as well as their mode of employment at the university (fulltime versus part time) turned out to be very important control variables. Further, and in line with previous research, we found a strong gender effect against top performance for women. But the evidence suggests that once women break through to their first top performance, no gender bias hinders them in further top performances[100]. Having access to large research funding speeds up the process towards top performance. In contrast, no convincing evidence was found of any age effect nor of any significant or sizeable impact of seniority on top productivity. Nevertheless, career incentives do matter: the likelihood of being a top performing researcher increases with rank. In this respect, heading a research lab also has a positive effect albeit marginally significant in the repeated events regressions. Teaching was not found to have a significant substitutive effect on research output. We also characterized the path towards top performance as gradual rather than abrupt, going against the "lucky strike" story for top performance. An important finding is the significant and accumulative impact of previous top output on the probability to repeat such an accomplishment, especially for women. Access to research funding is an important factor in this accumulative process. Finally, correcting for unobserved individual heterogeneity (talent) is important.

99 This is the baseline hazard corresponding to the repeated top performance model with a previous events counter. Other specifications show a similar pattern.

100 When looking at second or higher order top performance, conditional on having achieved a first top performance, the gender effect disappears (results not reported).

3.5.2 Logit Analysis of Top and Persistent Top

In the previous section we used a hazard analysis to look at the process to first and repeated top research performance. To check the robustness of our findings, we complete our analysis by analyzing the determinants of top performance and its persistency, using a logit model. The logit analysis examines which characteristics explain the probability to be selected into the top productivity category (using a two-year moving window) or the persistent top category (across the whole observation period).

Explaining selection into the top performance category

We start with an analysis of the probability to be in the top performance category. The estimated standard errors account for the fact that we have repeated observations for the individuals. The results are shown in table 3.11. The estimates are reported as risk ratios, relative to the middle and low output category.

The results confirm the hazard analysis of section 4. The relative “risk” of being in the top category versus an average or low output is significantly higher for males than for females. While age and seniority again have no significant impact, higher ranks are significantly more likely to be associated with top research performance, as well as being a head of unit and having access to research funding. For the funding effect, especially the big funds (type I) matter, again supporting the Matthew effect. Also the corrections for discipline, faculty and full-time position, as well the negative teaching load effect are reconfirmed.

Explaining selection into the persistent top performance category

In the logit analysis for persistent top, we collapse the time dimension in the data. For the rank, head of unit and project funding dummies we take for each researcher the first observed value within the window 1992-2001 in order to reduce endogeneity issues with respect to productivity during this period. For the age, seniority and teaching load variables, we take the average across observations.

Only researchers working fulltime at the university are retained as no part-timers enter the persistent top category[101].

The logit analysis runs into the problem of a more limited set of observations and a very skewed distribution, with only a limited number of non-zeros i.e. persistent top performers (57 versus 753 non-persistent top performers), which makes it hard to find significant effects and a good predictive model overall. The results, although less significant, nevertheless confirm the hazard analysis results.

The initial observed rank is significant for explaining persistency at the top: all ranks have a significant and strong negative probability of being top in every period of observation compared to the most senior rank. The scientists receiving project funding the first time we observe them have a leg up on those not receiving funding. More specifically, the large type I funding increases the odds of being a persistent top performer, although significant only at 10%. Teaching load shows up marginally significant, with a small negative effect on persistency of top performance. Although the gender effect showed up as sizeable and very significant in our hazard analysis for first top performance, it was less strong in repeated top performance. In line with this finding, the gender differential fades out in the logit analysis for persistent top performance. Also head of unit status in the first observation is no longer significant, which is consistent with the earlier observation that heading a research unit was found to contribute primarily to first top performance but is of lesser importance to explain subsequent top performances. Age does not matter for explaining persistency (nor for first or repeated top performance). The corrections for scientific discipline, faculty membership and entry cohort are less important for explaining persistency.

[101] In fact, two part-timers do enter the persistent top category. We found indications (based on additional checks on the web) that they are also affiliated to another university, presumably leading to a full-time academic position. To be safe, we exclude them from the analysis. Note that even if we didn't exclude them, being parttime would still be an almost perfect predictor of not being in the persistent top category, suggesting that parttime and fulltime researchers have a very different profile.

3.6 Conclusions and Further Research

The paper uses a panel dataset comprising the publications of biomedical and exact scientists at the KU Leuven in the period 1992-2001, to study the process towards and selection in the top scientific performance category. We study both first and subsequent top performances. Analysing the characteristics explaining the process towards top performance and its persistency, using hazard and logit analysis, we contribute to the debate on cumulative advantage effects in academic research.

About one quarter of the scientists in the sample achieves top performance at least once in the observation period, with six out of a hundred scientists being persistently top. Using mobility matrices, we find that top productivity generally is persistent over time: previous top performers are more likely to reach top status in next periods.

A hazard model predicting the time towards first top performance confirms the importance of gender, with females being significantly less likely to reach top performance. Age and seniority effects are not significant, but rank and hierarchical position, as well as access to excellence funding are important for explaining the hazard to first top performance. There is only limited evidence with respect to the substitution effect of teaching load on top research performance. Correction for scientific discipline, full time position and organizational membership is important. Low previous performers are less likely to reach top status, confirming that first top performance is a gradual, accumulative process, as the Matthew effect or a learning perspective would predict.

When analyzing subsequent top performances, we find strong support for the accumulative process, with the hazard to next top performance being significantly and increasingly positively affected by previous top performance. Rank is important not only in predicting first top performance, but also for persistency in top performance, supporting the accumulative effect. Also the gender bias remains significant in explaining subsequent top performance, but this time with the dependence on previous top performance in favor of females, suggesting that the gender effect is mainly a selection problem into first top. While funding and head of unit position are important for selecting into first top performance, they are less predictive for subsequent top performance. And finally, the correction for unobservable individual heterogeneity, like ability, is significant, suggesting that talent remains an integral part of the story of top performance and its persistence.

Although the current analysis provides interesting results with respect to top performance and its persistence, it also suggests exciting avenues for further analysis. A first important extension, suggested by the significance of organizational affiliation dummies of the current analysis, is to examine the collective effects in more detail, by specifying characteristics of the research teams and networks to which the researcher is affiliated, and with whom she cooperates in research through co-publications, within KU Leuven but also beyond. Further analysis should also properly take into account the substitution - or complementarity - among the various output dimensions for researchers: basic research, teaching but also applied research and own commercialization (patents and spin-offs). Also the trade-off between quantity and quality of research output can be investigated in more detail. While the current analysis has focused on establishing top performance and its persistence in terms of quantity of publications, we can extend and compare the analysis taking on board the quality of publications dimension, using citation information. Furthermore, by examining whether publications that yield more peer recognition, through citations, are more likely to establish persistence in performance we can study the processes governing the Matthew effect more carefully. And this brings us to perhaps the most important extension suggested by the current analysis, namely to further characterize the accumulative process of persistent top performance. Besides promotion, access to infrastructure and team membership, another important component of the accumulative advantage story is research funding, as the results presented here have indicated. To characterize the role of funding further, a wider array of funding sources (external funding organizations at regional, national and European level as well as contract research) should be added. In addition, when including funding and other accumulation components in the performance analysis, the endogeneity needs to be properly taken into account by including an instruments or systems approach.

Finally, an important limitation of this work is the scope of the data since we consider the KU Leuven only. Comparison of results with other institutions would be very valuable to improve on institutional heterogeneity.

3.7 Tables & Figures

Table 3.1: Distribution of researchers over organizational units

Organizational Unit	Freq.	Percent
Group Exact Sciences	483	46.9
Faculty of Science	192	18.6
Faculty of Engineering	214	20.8
Faculty of Applied Bioscience and Engineering	77	7.5
Group Biomedical Sciences	547	53.1
Faculty of Medicine	460	44.7
Faculty of Pharmaceutical Sciences	36	3.5
Faculty of Physical Education & Kinesiology	51	5.0
Total	1030*	100.0

* Six people switched between groups and/or faculties in the period 1992-2001 and are not shown in this table.

Table 3.2: Distribution of researchers over disciplines

Main Discipline	Freq.	Percent
None (inactive researchers)	222	21.5
Clinical and Experimental Medicine II (Non-internal Medicine Specialties)	190	18.4
Clinical and Experimental Medicine I (General & Internal Medicine)	157	15.2
Biosciences (General, Cellular & Subcellular Biology; Genetics)	91	8.8
Chemistry	86	8.3
Engineering	72	7.0
Physics	65	6.3
Agriculture & environment	36	3.5
Biology (Organismic & Supraorganismic level)	31	3.0
Biomedical research	26	2.5
Mathematics	26	2.5
Geosciences & space sciences	19	1.8
Neuroscience & behavior	13	1.3
Total	1034*	100.0

* Two researchers had a tie in terms of their number of publications for two or more disciplines and are not shown.

Table 3.3: Individual and career-related variables by persistence category (yearly averages)

Variable	Whole sample		Persistent top	Non-persistent Top	Average	Inactive
	mean	s.d.	mean	mean	mean	mean
Male	0.89	0.32	0.93	0.94	0.87	0.86
Age	47.74	8.98	47.84	46.68	46.83	50.95
% age cohort 1 (age<40)	0.25	0.38	0.25	0.26	0.28	0.16
% age cohort 2 (40≤age<50)	0.32	0.36	0.31	0.35	0.33	0.26
% age cohort 3 (50≤age<60)	0.31	0.37	0.29	0.31	0.29	0.35
% age cohort 4 (60<age)	0.13	0.29	0.15	0.08	0.11	0.24
Entry cohort*						
% entry cohort 1 (1955-1980)	0.19	0.39	0.33	0.20	0.17	0.18
% entry cohort 2 (1981-1988)	0.19	0.39	0.24	0.31	0.15	0.14
% entry cohort 3 (1989-1991)	0.24	0.43	0.07	0.24	0.26	0.23
% entry cohort 4 (1992-...)	0.38	0.49	0.36	0.25	0.42	0.45
Years of employment in 1992-2001	7.51	2.88	6.61	8.95	7.45	6.48
Fulltime at university	0.80	0.38	0.98	0.97	0.86	0.47
Rank**						
% rank 1 (junior)	0.24	0.03	0.10	0.12	0.27	0.37
% rank 2	0.22	0.02	0.06	0.15	0.25	0.28
% rank 3	0.16	0.03	0.09	0.19	0.17	0.13
% rank 4 (senior)	0.25	0.02	0.62	0.37	0.20	0.14
Rank seniority***	5.71	6.69	8.62	5.85	5.37	5.64
rank 1 (junior)	2.41	2.26	0.93	1.88	2.28	3.01
rank 2	3.10	2.68	1.30	2.14	3.17	3.75
rank 3	4.25	5.00	4.08	3.01	4.55	5.77
rank 4 (senior)	12.26	8.51	11.78	10.28	13.02	16.97
Teaching load (year-hours)	4.18	4.09	4.51	4.75	4.16	3.38
rank 1 (junior)	1.49	1.77	1.04	1.35	1.42	1.72
rank 2	3.08	3.11	3.56	2.97	3.20	2.81
rank 3	4.95	3.67	2.66	4.03	5.61	4.81
rank 4 (senior)	7.96	4.40	5.75	7.85	8.67	8.31
Project funding						
% with type I funding	0.09	0.24	0.22	0.20	0.07	0.00
as promoter	0.03	0.13	0.13	0.06	0.01	0.00
as co-promoter	0.07	0.20	0.09	0.14	0.06	0.00
% with type II funding	0.11	0.23	0.18	0.16	0.11	0.02
as promoter	0.06	0.17	0.08	0.09	0.07	0.01
as co-promoter	0.05	0.15	0.11	0.08	0.04	0.01
N	1036		61	218	535	222

* For 44 researchers this information is missing.
** Only the four main ranks shown. People may be in other ranks which are of lesser concern here (e.g. 'jury member PhD') or may combine one of these other ranks with one of the main ranks.
*** This is the expected rank seniority for someone in a given rank; not the total number of years scientists tend to spend in each rank.

Table 3.4: Research output by discipline (yearly averages), for active researchers only (N=814)

Main discipline	Publications per author	Co-authors per publication	Citations per publication*	Citations per publication$^{**}_{world}$	Impact measure per publication
Agriculture and Environment	3.5	3.3	1.6	1.8	1.7
Biosciences	7.5	5.7	8.6	7.5	6.5
Chemistry	5.5	3.8	3.2	2.8	3.1
Engineering	2.1	2.9	1.0	1.1	1.1
Geosciences and Space Sciences	2.5	3.9	2.1	3.0	2.6
Mathematics	1.8	1.8	1.0	1.0	0.9
Clinical and Experimental Medicine I	5.4	6.0	5.6	5.0	4.0
Clinical and Experimental Medicine II	3.3	5.0	2.8	2.8	2.5
Neuroscience and Behavior	3.0	3.3	3.4	5.5	5.4
Physics	5.2	5.1	2.7	3.1	3.0
Biomedical Research	4.1	4.4	4.4	4.0	4.0
Biology	4.0	3.9	4.0	3.3	3.8
Total	4.4	4.8	3.8	3.4	3.4
(s.d.)	(6.38)	(5.62)	(6.63)		(3.19)

* The average number of citations received by a paper in a 3-year forward citation window, for papers published by KU Leuven researchers in 1992-2001
** The average number of citations received by a paper in a 3-year forward citation window, for papers published in 1992-2001 at the world level (source: Center for R&D Statistics, Leuven, based on ISI-data)

Table 3.5: Mobility matrix for 1992/1993 - 1993/1994

Performance in 1992/1993		Performance in 1993/1994 low	medium	top	Total
low	freq.	301	23	2	326
	%	92.3	7.1	0.6	100
medium	freq.	36	125	17	178
	%	20.2	70.2	9.6	100
top	freq.	8	20	89	117
	%	6.8	17.1	76.1	100
Total	freq.	345	168	108	621
	%	55.6	27.1	17.4	100

Pearson chi2(4) = 635.14

Performance measure used = number of publications
Number of exits (researchers present in 92, but not in 93): 26
Number of entries (researchers not present in 92, but present in 93): 58

Table 3.6: Research output by persistence category (yearly averages)

Variable	Whole sample	Persistent top	Non-persistent top	Average	Inactive
Number of researchers	1,036	61	218	535	222
%	100.0	5.9	21.0	51.6	21.4
Publications per author	3.3 (5.1)	14.3	6.6	2.2	n/a
Co-authors per publication	4.7 (3.7)	4.9	4.6	4.8	n/a
Citations per publication	3.0 (4.2)	5.1	4.5	3.4	n/a
Impact measure per publication	3.2 (2.4)	3.0	3.2	3.1	n/a
(co-)Promoted PhDs	0.3 (0.5)	0.8	0.5	0.2	0.0

Standard deviations in brackets

Table 3.7: Output of persistent top researchers at KU Leuven with world average (citations/publication by discipline)

Main discipline	Persistent top researchers at KU Leuven (N=61) Number of researchers	Citations per publication*	(Citations per publication)$_{World**}$
Agriculture and Environment	4	24.1	1.8
Biosciences	6	241.8	7.5
Chemistry	7	70.4	2.8
Engineering	5	13.8	1.1
Geosciences and Space Sciences	2	66.7	3.0
Mathematics	2	11.7	1.0
Clinical and Experimental Medicine I	11	134.9	5.0
Clinical and Experimental Medicine II	17	29.4	2.8
Neuroscience and Behavior	1	85.4	5.5
Physics	3	102.5	3.1
Biomedical Research	1	11.5	4.0
Biology	2	102.9	3.3

* The average number of citations received by a paper in a 3-year forward citation window, for papers published by KU Leuven researchers in 1992-2001
** The average number of citations received by a paper in a 3-year forward citation window, for papers published in 1992-2001 at the world level (source: Center for R&D Statistics, Leuven, based on ISI-data)

Table 3.8: Cox models for first top performance

	First top performance		Path to first top performance	
	Haz. Ratio	z	Haz. Ratio	z
male	1.86**	(2.06)	1.17	(0.43)
age	0.91	(-0.89)	0.87	(-0.87)
age squared	1.00	(0.14)	1.00	(0.50)
main discipline				
biosciences	1.51	(1.07)	0.36	(-1.09)
chemistry	4.37***	(4.21)	2.69	(1.29)
engineering	4.04***	(3.32)	4.67**	(2.04)
geosciences	6.51***	(3.63)	9.19**	(2.11)
mathematics	5.69***	(4.03)	5.44*	(1.90)
medicine I	2.73***	(3.15)	2.24	(1.33)
medicine II	3.58***	(4.09)	3.31**	(2.00)
neuroscience	7.30***	(4.18)	11.10***	(3.17)
physics	5.61***	(4.47)	7.83***	(2.79)
biomedical	3.25**	(2.42)	3.87*	(1.84)
biology	2.25	(1.61)	4.67**	(2.26)
faculty membership				
fac of science	1.99	(1.44)	0.96	(-0.06)
fac of engineering	1.53	(0.88)	0.89	(-0.19)
fac of agriculture	3.97***	(2.70)	1.59	(0.71)
fac of medicine	3.85***	(3.22)	2.21*	(1.67)
fac of pharmacy	3.23**	(2.37)	1.92	(0.92)
rank				
rank 1 in t-1	0.13***	(-6.45)	0.10***	(-5.53)
rank 2 in t-1	0.24***	(-6.92)	0.16***	(-5.14)
rank 3 in t-1	0.36***	(-4.41)	0.38***	(-3.26)
other rank in t-1	0.41***	(-3.04)	0.33**	(-2.32)
seniority in rank	0.98	(-1.10)	0.99	(-0.36)
head of unit in t-1	1.52**	(2.51)	1.94***	(2.86)
fulltime at university	3.34***	(2.99)	1.51	(0.92)
entry as professor $\geq$ 1992	1.63**	(2.02)	1.83*	(1.90)
career age	1.02	(1.01)	0.99	(-0.23)
teaching load	0.96*	(-1.82)	0.96	(-1.18)
project funding				
type I funding in t-1	1.77***	(2.78)	0.85	(-0.43)
type II funding in t-1	0.92	(-0.36)	0.55**	(-2.01)
middle performance category in t-1			6.49***	(6.43)
N	4423.00		3935.00	
ll	-1173.30		-584.02	
chi2	287.29		231.57	

Base categories: agriculture & environment (main discipline), faculty of physical education & kinesiology (faculty membership), rank 4 (rank)
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 3.9: Cox models for repeated top performance

	Repeated top performance		Repeated top performance, with previous events counter		Repeated top performance, with previous event counter dummies	
	Haz. Ratio	z	Haz. Ratio	z	Haz. Ratio	z
male	2.11***	(2.82)	1.59**	(1.96)	1.49**	(2.15)
age	0.93	(-0.86)	0.91	(-1.33)	0.90**	(-2.05)
age squared	1.00	(0.14)	1.00	(0.55)	1.00	(1.32)
main discipline						
biosciences	0.98	(-0.07)	1.61*	(1.89)	1.26	(1.16)
chemistry	2.90***	(3.52)	3.10***	(5.42)	2.11***	(4.41)
engineering	3.91***	(4.05)	3.04***	(4.37)	2.09***	(3.47)
geosciences	4.05***	(3.20)	2.47***	(2.93)	1.82**	(2.03)
mathematics	5.06***	(4.45)	3.69***	(5.18)	2.17***	(3.47)
medicine I	1.65*	(1.73)	2.06***	(3.20)	1.62***	(2.70)
medicine II	2.43***	(3.14)	2.67***	(4.40)	1.85***	(3.41)
neuroscience	3.22***	(2.58)	3.20***	(3.13)	2.49***	(3.66)
physics	4.19***	(4.25)	3.91***	(4.96)	2.87***	(4.80)
biomedical	2.06*	(1.80)	2.25***	(2.59)	1.60*	(1.90)
biology	1.36	(0.64)	1.72	(1.55)	1.84**	(2.30)
faculty membership						
fac of science	1.56	(0.98)	1.31	(0.69)	0.94	(-0.19)
fac of engineering	1.41	(0.78)	1.14	(0.34)	1.04	(0.14)
fac of agriculture	4.22***	(3.19)	2.94***	(2.69)	2.18***	(2.66)
fac of medicine	3.79***	(3.46)	2.34**	(2.40)	1.83**	(2.32)
fac of pharmacy	3.44***	(2.65)	1.93	(1.62)	1.54	(1.52)
rank						
rank 1 in t-1	0.12***	(-10.34)	0.21***	(-8.19)	0.41***	(-5.99)
rank 2 in t-1	0.21***	(-9.14)	0.42***	(-5.70)	0.56***	(-4.82)
rank 3 in t-1	0.36***	(-7.22)	0.63***	(-3.96)	0.72***	(-3.56)
other rank in t-1	0.50***	(-2.95)	0.67**	(-2.36)	0.82	(-1.43)
seniority in rank	0.98	(-0.99)	0.98	(-1.46)	0.99	(-1.40)
head of unit in t-1	1.22*	(1.85)	1.16	(1.63)	1.09	(1.27)
fulltime at university	4.79***	(4.23)	3.54***	(3.68)	2.79***	(3.05)
entry as professor $\geq$ 1992	1.18	(0.88)	1.45**	(2.56)	1.31**	(2.38)
career age	1.02	(1.31)	1.02**	(2.04)	1.02*	(1.82)
teaching load	0.94***	(-3.48)	0.99	(-0.77)	1.00	(-0.51)
project funding						
type I funding	1.54***	(2.75)	1.11	(0.94)	1.07	(0.68)
type II funding	1.26**	(2.06)	1.02	(0.21)	1.10	(1.27)
previous top performances						
nr previous top performances			1.52***	(16.89)		
nr previous top perf's = 1					13.67***	(23.23)
nr previous top perf's = 2					9.40***	(16.02)
nr previous top perf's = 3					15.48***	(18.74)
nr previous top perf's = 4					17.07***	(18.47)
nr previous top perf's = 5					19.39***	(19.23)
nr previous top perf's = 6					21.99***	(19.74)
nr previous top perf's = 7					24.48***	(19.34)
nr previous top perf's = 8					26.54***	(18.24)
N	5562		5562		5562	
ll	-5343.58		-5136.85		-4942.66	
chi2	498.75		893.41		1565.56	

base categories: rank4 (rank), faculty of physical educ. & kinesiology (faculty membership), agriculture & environment (main discipline), nr previous top perf's = 0 (event counter dummies)

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 3.10: Cox models for repeated top performance with frailty

	Repeated top performance, with previous events counter		Repeated top performance, with previous events counter and frailty		Repeated top performance, with previous events counter, individual frailties and gender interaction	
	Haz. Ratio	z	Haz. Ratio	z	Haz. Ratio	z
male	1.59**	(1.96)	1.66**	(2.00)	2.32***	(2.88)
age	0.91	(-1.33)	0.98	(-0.28)	0.96	(-0.47)
age squared	1.00	(0.55)	1.00	(-0.55)	1.00	(-0.35)
main discipline						
biosciences	1.61*	(1.89)	1.91*	(1.87)	1.94*	(1.94)
chemistry	3.10***	(5.42)	4.63***	(4.89)	4.45***	(4.86)
engineering	3.04***	(4.37)	4.85***	(4.28)	4.66***	(4.26)
geosciences	2.47***	(2.93)	5.12***	(3.28)	4.90***	(3.26)
mathematics	3.69***	(5.18)	5.85***	(4.48)	5.66***	(4.50)
medicine I	2.06***	(3.20)	2.59***	(2.92)	2.67***	(3.05)
medicine II	2.67***	(4.40)	3.87***	(4.29)	3.89***	(4.37)
neuroscience	3.20***	(3.13)	7.24***	(4.05)	7.03***	(4.08)
physics	3.91***	(4.96)	7.36***	(5.63)	6.97***	(5.59)
biomedical	2.25***	(2.59)	3.10***	(2.64)	3.09***	(2.69)
biology	1.72	(1.55)	2.94***	(2.90)	2.44**	(2.40)
faculty membership						
fac of science	1.31	(0.69)	1.39	(0.80)	1.44	(0.90)
fac of engineering	1.14	(0.34)	1.25	(0.52)	1.28	(0.58)
fac of agriculture	2.94***	(2.69)	4.16***	(3.24)	4.21***	(3.33)
fac of medicine	2.34**	(2.40)	3.16***	(3.30)	3.06***	(3.27)
fac of pharmacy	1.93	(1.62)	2.63**	(2.12)	2.67**	(2.20)
rank						
rank 1 in t-1	0.21***	(-8.19)	0.18***	(-6.89)	0.18***	(-6.97)
rank 2 in t-1	0.42***	(-5.70)	0.36***	(-5.71)	0.35***	(-5.88)
rank 3 in t-1	0.63***	(-3.96)	0.52***	(-4.35)	0.52***	(-4.40)
other rank in t-1	0.67**	(-2.36)	0.60**	(-2.53)	0.60**	(-2.57)
seniority in rank	0.98	(-1.46)	0.98	(-1.32)	0.98	(-1.30)
head of unit in t-1	1.16	(1.63)	1.17	(1.48)	1.15	(1.35)
fulltime at university	3.54***	(3.68)	3.68***	(4.59)	3.62***	(4.57)
entry as professor $\geq$ 1992	1.45**	(2.56)	1.42*	(1.86)	1.36*	(1.67)
career age	1.02**	(2.04)	1.04**	(2.32)	1.04**	(2.16)
teaching load	0.99	(-0.77)	0.98	(-1.44)	0.98	(-1.41)
project funding						
type I funding in t-1	1.11	(0.94)	1.23	(1.51)	1.25	(1.63)
type II funding in t-1	1.02	(0.21)	1.06	(0.46)	1.07	(0.57)
nr previous top performances	1.52***	(16.89)	1.29***	(8.99)	2.33***	(4.19)
male * nr previous top performances					0.56***	(-2.89)
theta			0.93$^{\triangle}$		0.84$^{♠}$	
N	5562		5562		5562	
ll	-5136.85		-5117.46		-5113.52	
chi2	893.41		337.02		361.54	

base categories: rank4 (rank), faculty of physical educ. & kinesiology (faculty membership), agriculture & environment (main discipline)

$^{\triangle}$ Likelihood-ratio test of theta=0: chibar2(01) = 38.77

♠ Likelihood-ratio test of theta=0: chibar2(01) = 31.87

* p<0.10, ** p<0.05, *** p<0.01

Table 3.11: Logit regression results

	Temporal top performance (by 2-year moving window)		Persistent top performance	
	Odds Ratio	z	Odds Ratio	z
male	2.35***	(2.62)	1.24	(0.37)
age	0.95	(-0.42)	0.92	(-0.33)
age squared	1.00	(-0.22)	1.00	(0.02)
main discipline[1]				
biosciences	0.60	(-0.99)	0.83	(-0.22)
chemistry	3.87***	(3.12)	2.86	(1.38)
engineering	5.94***	(3.83)	3.98	(1.56)
geosciences	6.42***	(2.67)	3.74	(1.02)
maths	8.62***	(4.18)	3.95	(1.32)
medicine I	1.69	(1.37)	0.90	(-0.14)
medicine II	2.99***	(2.90)	1.99	(0.99)
neuroscience	9.72***	(3.80)	1.39	(0.22)
physics	6.79***	(4.12)	1.47	(0.37)
biomedical	2.32	(1.45)	0.76	(-0.22)
biology	1.59	(0.68)	1.66	(0.53)
faculty membership[2]				
fac of science	1.54	(0.76)		
fac of engineering	1.40	(0.59)	0.74	(-0.43)
fac of agriculture	6.04***	(2.95)	1.96	(0.89)
fac of medicine	5.87***	(3.64)	3.38*	(1.86)
fac of pharmacy	7.19***	(2.91)	4.14*	(1.66)
rank[3]				
rank 1	0.04***	(-9.66)	0.03***	(-4.55)
rank 2	0.08***	(-9.20)	0.08***	(-4.20)
rank 3	0.21***	(-7.03)	0.12***	(-3.17)
other rank	0.32***	(-2.94)	0.11***	(-2.60)
seniority in rank	0.98	(-0.80)	0.99	(-0.09)
head of unit[4]	1.41*	(1.93)	1.59	(1.10)
fulltime at university[5]	5.69***	(3.94)		
entry as professor >= 1992	1.32	(1.03)	1.59	(0.71)
career age	1.03	(1.11)	1.00	(0.02)
teaching load	0.90***	(-3.69)	0.90	(-1.56)
project funding[6]				
type I funding	2.17***	(2.81)	2.26*	(1.71)
type II funding	1.48**	(2.15)	1.79	(1.37)
constant	0.21	(-0.53)	5.75	(0.29)
N	5074		810	
ll	-1676.64		-172.11	
chi2	288.55		68.23	

[1] base category = agriculture & environment

[2] For the temporal top model, base category is the fac. of physical education & kinesiology. For the persistent top model, base category is the fac. of science + fac. of physical education & kinesiology (no persistent top researchers in the latter faculty).

[3] Base category = rank 4 (most senior rank). For the temporal top model, this indicates the rank in the previous period. For the persistent top model, this indicates the rank in the first observation period.

[4] For the temporal top model, this indicates head of unit status in the previous period. For the persistent top model, this indicates head of unit status in the first observation period.

[5] For the persistent top model, we only consider fulltime researchers.

[6] For the temporal top model, this indicates funding status in the previous period. For the persistent top model, this indicates whether the researcher had the funding in the first observation period in 1992-2001 or before 1992 (funding data goes back to 1983).

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

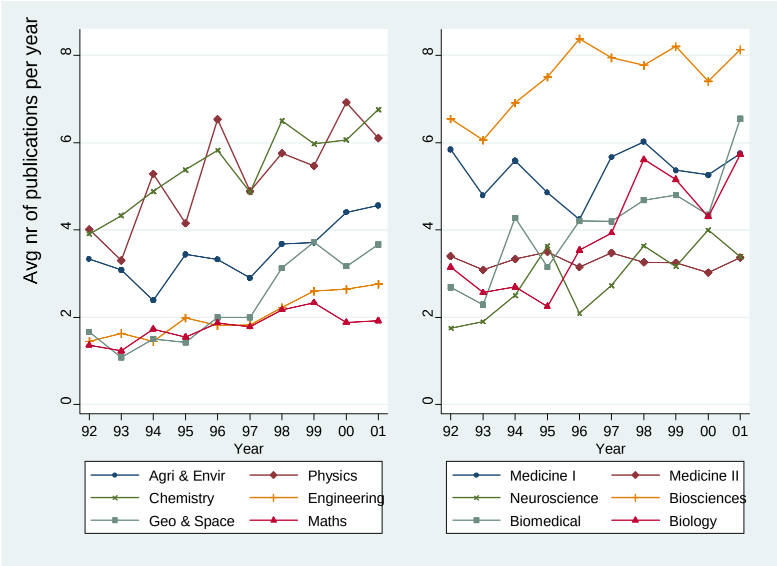

Figure 3.1: Evolution of publication activity by discipline (1992-2001)

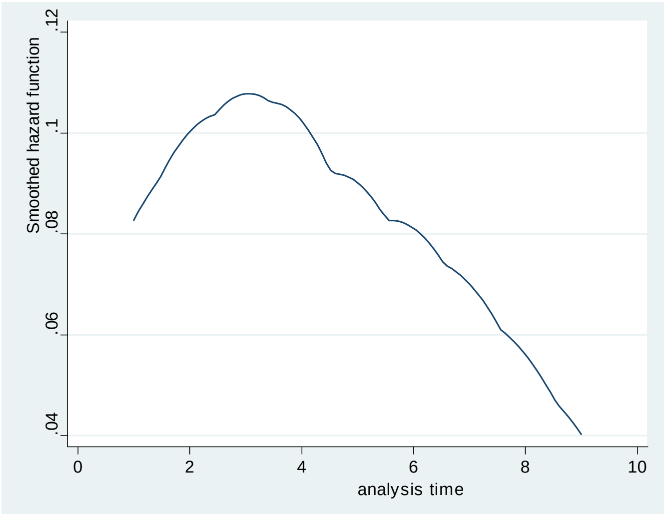

Figure 3.2: Baseline hazard for repeated top performance

3.A Appendices

3.A.1 Appendix 1. Constructing the database

The publication and citation data originate from the Science Citation Index (SCI) of the Institute of Scientific Information (ISI). As there is no one-to-one matching between authors and their affiliation address in the ISI data, publications in each of the ten yearly publication files were initially retained when at least one author was affiliated with the KU Leuven so that a number of non-KU Leuven related authors remained present. In a second step, we narrowed the number of publication records by means of a merge with the KU Leuven personnel files in order to only retain KU Leuven affiliated authors (see infra).

Since the ISI records do not allow distinguishing between primary- and co-authorship, we used a "full integer" counting scheme for calculating the performance data. This means that a publication was counted as "1" for all authors of the paper. The same goes for citations: the full number of citations was added to the credits of each author of the paper, whereby an author was identified by his or her surname plus the first initial. This gives rise to homonyms: within the yearly publication files it is not possible to distinguish between authors that have the same name. As discussed below, most of these homonyms could be resolved during the merge with the university personnel file.

Because a researcher's last name plus the first initial is the only piece of information that is shared between the ISI publication records and the university personnel file, the two datasets were combined using this key. In this way, the non-KU Leuven affiliated researchers that were still present in the dataset but whose name did not occur in the personnel files were filtered out. Before carrying out this merge operation, 45 homonyms were dropped from the KU Leuven personnel file since we could not distinguish between these staff members. However, this does not completely rule out mistakes due to homonyms during the merge of the two files. In particular, although homonyms were removed from the personnel file, it is still possible that a homonym occurs between a KU Leuven affiliated author and an external authors within the publications file. Because the name occurs in the personnel file, the publication data of both these author records will be mapped on the staff record, biasing upwards the performance of the staff member. Because the ISI records do not allow linking authors unambiguously to their affiliation, this problem cannot be resolved nor can its magnitude be estimated. We deem it to be a minor issue though, and point out that the merge key used inherently mitigates the problem since researchers with identically spelled last names but a different initial do not yield a 'false positive'.

3.A.2 Appendix 2. The Katholieke Universiteit Leuven

Founded in 1425, the Katholieke Universiteit Leuven (KU Leuven) is the oldest and largest university in Flanders and Belgium, encompassing all academic disciplines. About 1,400 tenured professors and more than 3,500 researchers are currently employed at KU Leuven, which has a student population of more than 30,000 students each year.

It has the legal status of a private institution, but receives most of its funding from the Belgian Government, both in a direct and in an indirect, competitive way. The basic public funding of the university, that pays for the salaries of the academic personnel, has remained roughly stable in the last decade, which has resulted in a more or less stable total number of professors at KU Leuven. The funding for research on the other hand has increased continuously. Most of this funding is obtained on a competitive basis: about one quarter is private funding from industry, about half comes from project funding from national, regional and EU governments and about one quarter is from the regional government allocated to the KU Leuven based on its share of regional publications, citations and PhDs. The latter funding is redistributed within the KU Leuven on a competitive basis. We have data on two major types of projects. "Type I" projects[102] are intended to support research groups from all disciplines with demonstrated scientific value based on international peer reviews, publications and other indicators of scientific quality. Type I projects typi-

[102] The actual name of these funds is 'GOA' (Geconcerteerde Onderzoeksactie). We use the generic indication 'Type I' in the paper.

cally receive funding of around 900,000 Euros for a total duration of five years (up to 1,625,000 Euros if several research groups are involved). “Type II” projects[103] are somewhat more modest in set-up and are intended to stimulate potential for fundamental research. They can be awarded to individual researchers as well as research groups with a good track record in research or with the intention to start up a new line of research aiming at high quality output. Type II projects receive a maximum funding of 475,000 Euros for a total duration of four years. Both types of funding are allocated on the basis of competitive, external peer review evaluation of past team performance and project proposal. Of the pre-screened proposals that are allowed to pass the full procedure, less than 50% obtain funding.

The KU Leuven has as mission statement in the observed period to be among the top 25 European research universities in a wide number of scientific disciplines. But it aims to be among the top particularly in those disciplines in which it is already strong: biochemistry, biosciences, biomedical and several disciplines in medicine, among which are hematology, oncology and cardiology.

In terms of career structure, we distinguish between four main ranks, with rank 1 the entry level (“assistant professor”) and rank 4 the highest possible rank (“full professor”). KU Leuven offers tenure to assistant professors who successfully pass the judgment of their work in the years following their hiring. After this initial tenure decision, for which young professors are primarily evaluated on their research output as opposed to other activities, they can be promoted in successive ranks up to full professor based on their research and teaching performance, as well as duties performed within the university, with the latter typically gaining importance as one progresses through the ranks. While rank 2-4 have tenure, rank 1 are the untenured researchers. The power of the tenure decision is however limited, since in its still recent history of tenure track, the KUL has no or little records of not granting tenure.

While officially the *faculty* as organizational unit is mostly responsible for the teaching programs, and the *department* is the organizational unit for research

[103] The actual name of these funds is ’OT’ (Onderzoekstoelage). We use the generic indication ’Type II’ in the paper.

activities, in practice both hierarchical levels are intertwined, particularly with respect to recruiting and promotion of researchers. The faculty level has a higher hierarchical position, with the *dean* being a member of the *bureau* that decides on recruitment and promotion, on the basis of *advice* from the departments.

Chapter 4: The Great Divide in Scientific Productivity. Why the Average Scientist Does Not Exist

Abstract

We[104] use a quantile regression approach to estimate the effects of age, gender, funding, teaching load and other observed characteristics of academic researchers on the full distribution of research output. We employ recent advances in quantile regression that allow its application to count data, i.e. numbers of publications and citations. We account for unobserved heterogeneity of researchers by estimating a random-effects model, exploiting the panel nature of our dataset. Estimation of the model for a panel of biomedical and exact scientists at the KU Leuven in the period 1992-2001 shows strong support for our quantile regression approach, revealing the differential impact of regressors along the distribution. We also find that variables like funding, teaching load and cohort have a different impact on research quantity than on research quality.

4.1 Introduction

Research output plays an increasingly important role in funding and promotion decisions in science. Therefore, a lot of attention has been devoted to unraveling the determinants of research productivity, both at the level of the individual researcher and at more aggregate levels such as the research lab. Understanding what makes a researcher productive is of interest to administrators of research organizations as it allows for more informed decisions regarding the design of jobs, career paths, incentive systems, etc.

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[104] This chapter is joint work with Reinhilde Veugelers.

This paper starts from a well documented feature of the research productivity distribution, viz. its skewness (starting with the observation by Lotka, 1926). Despite this indication of substantial heterogeneity in the researcher population, studies that analyze research output tend to explain *average* productivity only. Previous work on research productivity has focused on how individual and institutional characteristics affect average productivity (see for example Stephan & Levin (1992) and Stephan (1996) for a survey). A recent exception is the paper by Rauber & Ursprung (2006) who find evidence of life-cycle effects in research for German economists using pooled quantile regressions. This paper focuses upon the estimation of the effects of a range of potential productivity drivers on the entire productivity distribution, at the level of individual researchers. Such an approach allows to determine, for example, whether the often observed "gender effect" operates consistently along the whole distribution versus at the lower or upper tail only. The characterization of the effect of a productivity driver can therefore be very informative with respect to the introduction, or the expected results, of policy measures by university administrators. In this paper we estimate the impact of a range of productivity drivers at several quantiles of the productivity distribution, looking at both quantity and quality of output. To allow for the estimation of the conditional quantiles of integer counts of publications and citations, we employ recent advances in the literature that extend the quantile regression approach to count data (Machado & Santos Silva, 2005).

An important issue is to accurately estimate the causal effect of the characteristics of researchers and their working environment on productivity. Unobserved heterogeneity among researchers makes it difficult to pin down the impact of several variables on research output. For example, whether a researcher has a high or low teaching load may be correlated with unobserved characteristics of the researcher. To deal with such difficulties one may use instrumental variable estimation to deal with potentially endogenous variables. Another approach is to use panel data in order to separate the individual effect of the researcher from the true impact of variables expected to affect productivity. Only recently efforts have been made to combine panel data techniques with quantile regression. The primary reason is the problem to apply the usual differencing approach to quantiles. Using Chamberlain's correlated random effects model (1982, 1984), we control for unobserved heterogeneity in the quantile estimations by allowing the researcher random effect to be related to the observed characteristics. For example, whether a professor carries a high teaching load or not, is likely to be correlated with unobserved characteristics such as a high affinity for teaching. By explicitly modeling the random effect as a function of teaching load (and other variables), we are able to identify the causal effect of teaching load on research output. Previous applications of the correlated random effects model in the context of quantile regression include Abrevaya & Dahl (2005), addressing the effect of smoking and prenatal care on infant birthweight. To our knowledge, this paper is the first effort to analyze research productivity using quantile regressions for panel data.

Using a panel of biomedical and exact scientists at the KU Leuven in the period 1992-2001, we find that the effect of most regressors differs significantly at different points in the distribution, yielding strong support for our quantile regression approach. This conclusion holds for both the quantity (publications) and quality (citations) distribution. These results allow to gain a fuller understanding of the role of productivity drivers compared to the classical approach where only the impact of a regressor on the conditional mean output is considered. This paper contributes to the economics of science literature on research productivity by estimating the impact of productivity determinants on the whole productivity distribution.

Furthermore, a formal test of the correlated random effects model clearly rejects a pure random effects approach where the random effects are assumed to be uncorrelated with the observables. For the variables that are taken up in the random effect specification, we thus successfully distinguish between their true effect and the part that is correlated with the (unobserved) individual effect of the researcher.

We also find that observables like funding, teaching load, gender and entry cohort have a different impact on the quantity distribution than on the quality distribution. These results have implications for science policy at the institutional level. In particular, this increased understanding of the research productivity process may assist in the putting forward the right expectations of a given science policy. For example, the impact of small research grants on research quality remains roughly constant across the distribution while the impact of this funding on research quantity is the highest at the bottom end of the distribution and then decreases monotonously towards the upper end. Although one must be cautious generalizing the results found here, this finding implies that an extreme selectivity in the assignment of research funds based on the argument that the researchers who were the most productive in the past "give the most bang for the buck" may be misdirected. Therefore, an understanding of the full productivity distribution may lead to better informed management decisions in research organizations.

The remainder of this paper is organized as follows. We start by discussing the data, providing details on the key aspects that we wish to address. The next section details the quantile regression approach motivated by the correlated random effects model, and the necessary adjustment to estimate conditional quantiles for count data. Section 4.4 discusses the empirical results, comparing the quantile estimates from the panel regressions with those from the cross-sectional approach. The final section summarizes and concludes.

4.2 The Data

We constructed a unique panel of 1,036 scientists within the fields of biomedical and exact sciences, in the period 1992-2001, employed at the KU Leuven, the largest and oldest university in Belgium. In terms of research, the KU Leuven has the ambition to establish a top position in "poles of excellence", and have a good performance in the other areas[105]. To this end it allocates research funding to research proposals on the basis of (international) peer review of excellence in research. Recruitment and promotion decisions also carry a strong research quality requirement. In addition, research output (quantity and quality) of its entire acad-

[105] For background on institutional features of the KU Leuven, see appendix 2 of chapter 3.

emic staff is regularly monitored (see Appendix 2 of chapter 3 for a description of the KU Leuven).

We pooled different sources of data sets, combining information from the personnel administration of the KU Leuven with bibliometric data[106]. The dataset contains the following information:

- Scientific output (per researcher per year[107]) i.e. publications in ISI journals classified by scientific discipline[108],[109];
- Individual and career-related variables (per researcher per year) i.e. gender, age, cohort (year of entry at KU Leuven), career age, rank (assistant professor, associate professor, professor and full professor), seniority in rank, full-time versus part time position;
- Organizational membership at group- (exact versus biomedical sciences), faculty- (e.g. medicine) and department (e.g. microbiology and immunology) level;
- Other information relevant for examining scientific performance, viz. *actual* teaching load, other administrative duties within KU Leuven, being head of a research unit, and involvement as a promoter or copromoter of research projects awarded on a competitive basis. Two major types of funding can be

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106 We refer to the appendix of a companion paper (Kelchtermans & Veugelers, 2005) for details on the construction of the database.

107 "Year" always refers to a "database year" i.e. the year in which the publication was taken up in the ISI records.

108 A key characteristic of the dataset is that it allows controlling for scientific discipline-specific effects: the KU Leuven Centre for R&D Statistics classified every journal covered by the SCI into one or more twelve high-level disciplines, all within the field of exact or biomedical sciences. This allowed us to assign to each scientist the disciplines in which she published a paper in that year. About 21% of all researchers could not be assigned to a main discipline because they did not publish in the period 1992-2001. For all others, we determined a 'main discipline' for each researcher, which is defined as the discipline, taken from the twelve high-level disciplines, in which the researcher has the most publications in the period 1992-2001. For 58 researchers there was a tie i.e. they published an equal amount of papers in at least two disciplines. For them we randomly assigned a main discipline from the tie disciplines. Table 4.2 shows the final distribution of the researchers in the sample over the disciplines.

109 There is also scientific output that does not fall under the scope of the Science Citation Index of the ISI. For instance, the ISI database does not include proceedings, which in some disciplines, like engineering, are an important publication outlet.

identified: the larger Type I (excellence) and the smaller Type II funding. See Appendix 2 of chapter 3 for a description of the KUL research strategy and the type of funding it awards.

Most researchers in the sample were not employed for the full 10 years: some of them retired or left the university before 2001, others joined after 1992. These entries and exits yield an unbalanced panel and allow examining cohort effects. The data set holds on average 778 researchers per year in an unbalanced panel[110].

We now briefly discuss descriptive statistics to introduce the data. First, Table 4.1 and table 4.2 present the distribution of scientists over the respective faculties and disciplines within the Biomedical and Exact Science groups of the KU Leuven. Both groups, each comprising three faculties, are comparable in size. Within the group of Exact Sciences, the faculty of Science (192 professors) and the one of Engineering (214) are the largest. In the group of Biomedical Sciences, the faculty of Medicine (460 professors) clearly dominates in terms of size. The vast majority of all researchers in the panel (94%) is professor and hence combines research and teaching activities. Most of them have or reach tenure in the observation period (78%). Considering both scientific discipline and organizational membership allows disentangling scientific discipline-specific influences from organizational and managerial effects.

As shown in Table 4.3, on average a researcher publishes 3.3 articles per year[111]. But this average has a high standard deviation (5.1). The propensity to publish varies greatly among disciplines: Table 4.4 shows the quantiles of the publication distribution by main discipline of the researcher. These quantiles are obtained by comparing the yearly publication output of all researchers who share the same main discipline[112] and are then averaged across years. The characterization of

110 Given our focus on persistence, we restricted the dataset to researchers whom we observe for at least 2 periods. For 97 researchers there was only one observation in the dataset; these were dropped, leaving 1,036 researchers.

111 A publication gets on average 3 citations and has an impact measure of 3.2. A scientist collaborates on a paper on average with 4.7 co-authors. She acts as as (co-)promoter of 0.3 PhD's per year.

112 Formally, the 100τth quantile of the publication distribution Y given x is given by $Q_Y(\tau|x) = \min\{\eta|P(Y \leq \eta|x) \geq \tau\}$.

the publication distribution in this table includes the output of the 814 researchers for whom we observe at least one publication in 1992-2001[113]. Although the 222 researchers with a persistently blank publication record are ignored here[114,115], note that the prevalence of zeroes is still very high, as can be observed by the small (differences in) percentile values at the bottom of the distribution. For most disciplines, in each year there is at least 10% of zero inflation, so that the 10^{th} percentile equals zero. For engineering, zero inflation even amounts to 25%. All this reflects the importance of scientific discipline specific effects when examining research productivity. Finally, the Lorenz curves in figure 4.1 confirm the skewed distribution of research quantity (publications) and show that the pattern for research quality (citations) is very similar[116].

Table 4.5 reports averages for the individual and career-related characteristics of the researchers, comparing the whole sample with the inactive versus the active reseachers. For the latter group we analyze the characteristics conditional on publication output, comparing different "percentile bands". Researchers are assigned to a percentile band as follows. Their publication output in a particular year is compared with the percentile values for their main discipline in that year[117] i.e. the values for which the yearly averages were reported in Table 4.4. For example, a researcher may publish enough articles in a given year to beat the 50^{th} percentile in her discipline but not enough to reach the 75th percentile: for that year, she is

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113 Active researchers tend to publish in several of the 10 disciplines. A researcher's main discipline is defined as the discipline in which she has published the most articles between 1992-2001. Consequently, inactive researchers i.e. for whom we don't observe any publications in 1992-2001, cannot be assigned a main discipline.

114 All researchers, including the 'persistent zeroes', are included in the empirical analysis later on.

115 Inspection of the data reveals that we can attribute this apparent 'inactivity' (at least partially) to the involvement of staff as practitioners in their field of expertise. In other words, some staff members may have a full-time position at the university but are nevertheless not expected to carry out research. In particular, there are four departments where more than one third of full-time staff doesn't show up in the ISI publication records. It concerns the departments of architecture, public health (where general physicians are trained), sports & motion sciences and kinesiology.

116 Citations are counted using a three-year forward citation window. The publication and citation counts were supplied by the Centre for R&D Statistics in Leuven, using ISI-data.

117 Note that this procedure, by comparing researchers with their peers in the same disicpline, controls for discipline-specific publication patterns and therefore avoids that researchers from disciplines characterized by lower publication rates are all classified in the lower percentiles.

classified in the 50%-75% percentile band[118], and in this band only[119]. Because a researcher's output may vary across years, she may be part of a different percentile band in each year, although researchers tend to be very immobile in their output levels (see Kelchtermans & Veugelers (2005), based on the same dataset). Note that persistently inactive researchers are not included in the determination of the yearly percentile values and therefore also kept separate from active researchers in the table, i.e. they are not added to the lowest percentile band.

In the whole sample about 89% of researchers are male. In line with previous studies on scientific productivity, we find that female researchers are overrepresented among the inactive and underrepresented among the most productive researchers. The inactive researchers seem older than average (47.7 years) but no clear age pattern emerges for the active researchers. On average, the youngest age cohort (professors less than 40 years old) constitutes one quarter of all researchers. The youngest cohort is underrepresented among the inactive researchers, the oldest cohort is overrepresented. For the active researchers the distribution over age cohorts at different points in the distribution seems roughly consistent with the distribution in the whole sample, again suggesting a minor role for age, if any. 38% of the researchers entered as a professor after 1992. Recent entry cohorts are overrepresented at the lower end of the distribution, while the situation is reversed at the upper end. A similar pattern emerges with respect to a rank. We distinguish between four main ranks, with rank 1 the entry level ("assistant professor") and rank 4 the highest possible rank ("full professor"). One quarter of researchers have the most junior rank, whilst about the same quantity have reached the top of the career ladder. The junior ranks are more prevalent in the lower half of the distribution. 80% of the scientists have a full-time position at the university either in one single contract or in a combination of several positions. For the upper half of conditional productivity distribution the proportion of full-time researchers rises to more than

[118] As mentioned, due to zero inflation it is possible that both the 10^{th} and 25^{th} percentile equal zero. In that case, researchers with zero publications are classified in the 10%-25% percentile band, leaving the $<$10% band empty.

[119] In other words, researchers are assigned to the highest percentile band they qualify for. So if a researcher's publication record in a given year 'beats' 52% of other publication records, she is classified in the 50%-75% percentile band.

90%. The average teaching load for a professor amounts to 4.18 year-hours[120] and increases monotonously with rank. The averages by percentile band do not suggest the substitution research output by teaching, on the contrary. On average 9% of the sample is involved in a type I project as a promoter or copromoter, while 11% (co-)promotes a type II project. Involvement in these research projects is strongly associated with research output.

4.3 Quantile regression framework

Section 4.3.1 starts by explaining why a simple differencing strategy is not an option to control for individual effects when the goal is to estimate conditional quantiles. As a solution, we specify a correlated random-effects model (Chamberlain, 1984). Section 4.3.2 discusses the smoothing approach that allows quantile regression for count data (Machado and Santos Silva, 2005).

4.3.1 Conditional quantiles of productivity with panel data

A standard linear panel-data model for our data may be written as:

$$Y_{it} = X_{it}'\beta + Z_{it}'\gamma + \alpha_i + \varepsilon_{it}$$

where $X_{it} = \left(x_{it}^1, \ldots, x_{it}^K\right)$ and $Z_{it} = \left(z_{it}^1, \ldots, z_{it}^G\right)$ are the vectors of observed characteristics with their associated parameter vectors $\beta = \left(\beta^1, \ldots, \beta^K\right)$ and $\gamma = \left(\gamma^1, \ldots, \gamma^G\right)$. X_{it} denotes the variables that are expected to correlate with the individual effect as opposed to those included in Z_{it} (this distinction is discussed further below). The unobserved individual effect is denoted by α_i and ε_{it} is the error term. It has been argued before in the literature (e.g. Fox, 1983) that the reason why some scientists are very prolific while others are not, may lie in the possession of a unique talent for research such as motivation and creativity. These idiosyncratic but unobserved characteristics are captured by the individual-specific effect α_i that

[120] A year-hour gives the average weekly teaching load in an academic year. One year-hour corresponds to 30 teaching hours.

is assumed to be stable over the sample period. Different assumptions for the unobserved individual effect lead to different flavors of panel-data models. The random effects model assumes that α_i is uncorrelated with X_{it}, an assumption which is usually hard to maintain in empirical applications. The fixed effects model allows α_i to be correlated with X_{it} in an unspecified way. In a least squares framework, β and γ can be consistently estimated by transforming Y, X and Z to deviations from individual means[121]. More specifically, because an expectation is a linear operator we can write $E\left(Y_{it} - \overline{Y}_i | X_i, Z_i\right) = E\left(Y_{it} | X_i, Z_i\right) - E\left(\overline{Y}_i | X_i, Z_i\right) = \left(X_{it} - \overline{X}_i\right)' \beta + \left(Z_{it} - \overline{Z}_i\right)' \gamma$ with $X_i \equiv (X_{i1}, ..., X_{iT})$ and $Z_i \equiv (Z_{i1}, ..., Z_{iT})$. This differencing approach is not available for quantile regressions since quantiles are not linear operators, the critical requirement for this strategy to work (Koenker & Hallock, 2001; Koenker, 2004). So in general $Q_\tau\left(Y_{it} - \overline{Y}_i | X_i, Z_i\right) \neq Q_\tau\left(Y_{it} | X_i, Z_i\right) - Q_\tau\left(\overline{Y}_i | X_i, Z_i\right)$, with $Q_\tau\left(Y | X\right)$ the τ-th conditional quantile function for $\tau \in (0, 1)$.

Two major options for estimating conditional quantiles accounting for individual effects exist in the literature. An approach proposed by Koenker (2004) consists of adding a penalty term to the quantile objective function as a way to impose structure on the fixed effects. While offering the advantage of leaving the relation between the fixed effect and the observables unspecified, the choice of the "tuning parameter" that controls the degree of structure is an open research issue. Recently, Lamarche (2006) has made progress in developing a selection mechanism for the value of this tuning parameter that minimizes the estimated asymptotic variance, provided an additional assumption for the individual effects distribution is made.

In this paper, we adopt a different approach. In line with other research (e.g. Levin and Stephan, 1991) we expect that the unobserved individual-specific effect is correlated with some of the determinants of research productivity. Therefore, we base our quantile regressions on Chamberlain's correlated random-effects model (1984), which employs a random effects specification that allows for such correlation. With this approach we are able to address potential endogeneity of time-varying variables with respect to the individual-specific effect. In particular,

121 Under the appropriate assumption i.e. $E\left(\varepsilon_{i1} | X_i, Z_i, \alpha_i\right) = ... = E(\varepsilon_{iT} | X_i, Z_i, \alpha_i) = 0 \ \forall i$

X_{it} denotes the time-varying variables for which we expect correlation with α_i. An example is teaching load: a researcher who dislikes teaching may actively avoid a heavy teaching load. The correlated random effects estimator uses a linear specification for the unobservable α_i consisting of the observables X_{it} plus an additional error term ν_i:

$$\alpha_i = \phi + \sum_{t=1}^{T} X'_{it}\lambda^t + \nu_i$$

where ϕ is a constant and ν_i is uncorrelated with X_{it} and $T \leq 10$[122]. We enter the following time-variant variables into the random effects specification: rank, seniority in rank, head of unit, additional project funding, number of coauthors and teaching load. This means that for each of these variables we are able to separate the direct effect β on the τ-th conditional quantile of research output from the indirect effects λ working through the unobservable α_i.

Note that the correlated random-effects model can not take into account potential correlation between time-invariant variables and the individual effect. We argue that the time-invariant variables considered in our model, viz. gender, cohort, research discipline and faculty membership, can be regarded as exogenous with respect to research productivity since they are not real "choice" variables. They are not under control of the individual researcher, or at least not to the same extent, as variables in X_{it} such as teaching load, number of co-authors, being the head of a research unit, etc. Also the time-variant variables age, career age and calendar year are considered exogenous in our model because they are not under control of the researcher. We use Z_{it} to denote the time-invariant variables as well as the time varying variables that are considered exogenous with respect to α_i. Section 4.3.3 gives a line-up of the variables that we include in X versus those included in Z.

Based on this correlated random-effects model, the conditional quantile functions are written as linear functions of the observables. For $t = 1$ the function for quantile τ is written as:

[122] Since we have an unbalanced panel, the number of observation periods varies by individual i (we observe an individual on average 7.5 years). To simplify notation, we write $T_i = T$. The estimates reported in section 4.4 use $T = 2$. Higher values of T do not alter the results.

$$Q_\tau\left(Y_{i1}|X_i,Z_i\right)=\phi_\tau+X'_{i1}\theta^1_\tau+\sum_{t=2}^{T}X'_{it}\lambda^t_\tau+Z'_{i1}\gamma^1_\tau \tag{4.1}$$

with $\theta^1_\tau=\beta^1_\tau+\lambda^1_\tau$. The conditional quantile functions for $t\neq 1$ are analogous to (4.1).

We impose the following restrictions to our empirical model:

- The direct effects of the variables X_i on the conditional quantiles are constant across time i.e. $\beta_\tau=\theta^t_\tau-\lambda^t_\tau \quad \forall t$. For example, the direct effect of teaching load on scientific output is assumed to be constant in every observation period.
- The effects of the variables Z_i on the conditional quantiles is constant across time: $\gamma^t_\tau=\gamma_\tau \quad \forall t$. For example, the impact of a researcher's discipline is assumed to be the same in every observation period.

We can rewrite (4.1) as:

$$Q_\tau\left(Y_{i1}|X_i,Z_{i1}\right)=\phi_\tau+X'_{i1}\beta_\tau+\sum_{t=1}^{T}X'_{it}\lambda^t_\tau+Z'_{i1}\gamma_\tau. \tag{4.2}$$

Again, the conditional quantile functions for $t\neq 1$ are analogous. A simple estimation strategy for (4.2) is by a pooled quantile regression on the stacked data, written as (for the τ-th quantile):

$$\begin{bmatrix} Y_{11}\\ \vdots\\ Y_{1T}\\ \vdots\\ Y_{N1}\\ \vdots\\ Y_{NT}\end{bmatrix}=\begin{bmatrix} 1 & X_{11} & X_{11} & \cdots & X_{1T} & Z_{11}\\ \vdots & & & & & \\ 1 & X_{1T} & X_{11} & \cdots & X_{1T} & Z_{1T}\\ \vdots & & & & & \\ 1 & X_{NT} & X_{N1} & \cdots & X_{NT} & Z_{N1}\\ \vdots & & & & & \\ 1 & X_{NT} & X_{N1} & \cdots & X_{NT} & Z_{NT}\end{bmatrix}\cdot\begin{bmatrix}\varphi_\tau\\ \beta_\tau\\ \lambda^1_\tau\\ \vdots\\ \lambda^T_\tau\\ \gamma_\tau\end{bmatrix}$$

The computation of the standard errors should account for the dependence between the repeated observations of a single researcher. This means that the standard formula for to calculate the asymptotic variance of the quantile estimators (Koenker & Bassett, 1978) cannot be applied. Following Abrevaya & Dahl (2005), we adopt a clustered bootstrapping procedure where the bootstrap sample contains all observations of a researcher if that researcher is drawn to be included in the bootstrap sample.

4.3.2 Quantile regression for count data

The main problem when estimating conditional quantiles for a count variable Y is that, because it has a discrete distribution, $Q_\tau(Y|X,Z)$ is not a continuous function of the parameters. To be able to apply quantile regression to count data, artificial smoothness must be imposed. Machado and Santos Silva (2005) suggest a "jittering approach" where the needed smoothness is achieved by adding to the count variable Y a random variable U, leading to a new variable $V = Y + U$. U is independent of Y, X and Z and uniformly distributed in the interval $[0,1)$. The authors show that it is possible to perform inferences about $Q_\tau(V|X,Z)$, the conditional quantile function of the smoothed data. Further, they relate the quantiles of the random variables V and Y, which is crucial since the ultimate interest lies in the quantile function of the original count data:

$$Q_\tau(V|X,Z) = Q_\tau(Y|X,Z) + \frac{\tau - \sum_{y=0}^{Q_\tau(Y|X,Z)-1} P(Y=y|X,Z)}{P(Y = Q_\tau(Y|X,Z)|X,Z)} \tag{4.3}$$

Thus, a continuous distribution is achieved by interpolating the discrete jumps in the conditional quantile function of the counts. $Q_\tau(V|X,Z)$ can be estimated using standard quantile regression techniques[123].

Alternatively, by rewriting (4.2), the conditional quantile function of V for $t=1$ can be written as[124]:

$$Q_\tau(V_{i1}|X_i, Z_{i1}) = \widetilde{\phi}_\tau + X_{i1}'\widetilde{\beta}_\tau + \sum_{t=1}^{T} X_{it}'\widetilde{\lambda}_\tau^t + Z_{i1}'\widetilde{\gamma}_\tau \tag{4.4}$$

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[123] In particular, several jittered samples are generated and used for estimation, after wich the estimates are averaged to yield the final parameters

[124] Machado & Santos Silva (2005) impose an additional restriction on the quantile process of the smoothed variable V by first applying a monotone transformation to V. The transformed V is then specified to be a linear function of the regressors, rather than specifying V itself as a linear quantile function as in (4.4). We abstract from this transformation in our exposition for simplicity.

with the conditional quantile functions for $t \neq 1$ analogous.

Finally, we point out that this approach is particularly useful to analyze the lower end of the research output distribution. Let x_{it}^k denote the k-th element from X_{it} and β_τ^k the k-th element from β_τ. Expression (4.3) shows[125] that if $\widetilde{\beta}_\tau^k \neq 0$, then the probability distribution at or below $Q_\tau(Y|X,Z)$ depends on x_{it}^k. Note that it is possible that for a given quantile, say τ_0, $\widetilde{\beta}_{\tau_0}^k \neq 0$ and yet a change in x_{it}^k does not impact the τ_0-th quantile of the *count variable* Y. An example of this occurs when the data is characterized by zero inflation, which is the case for the publication and citation output we study here. Specifically, in a dataset with $100 \times \theta$ percent of zero inflation, all of the quantiles of Y up to $\tau = \theta$ will be identically zero, even if the corresponding quantiles of V depend on x_{it}^k. Therefore, it is easier to pick up dependence of the distribution of Y on X and Z by looking at $Q_\tau(V|X,Z)$ than by looking at $Q_\tau(Y|X,Z)$. Machado & Santos Silva (2005) refer to this as the "magnifying glass effect" of $Q_\tau(V|X,Z)$. Given the skewness of the productivity distribution for both publications and citations, this represents a considerable advantage as it allows studying the lower part of the distribution.

4.3.3 Variables

Our empirical analysis investigates the impact of a series of variables on different quantiles of productivity. First, we indicate for each of these variables the expected impact on average output based on the findings of previous research. We hypothesize a single effect that is expected to hold for both quantity and quality of research output, based on the correlation between these two output measures[126]. The variables are grouped depending on whether they are part of the random effect specification (see section 4.3.1). Subsequently, we formulate a hypothesis with respect to the differential impact of these variables along the productivity distribution.

The following characteristics are taken up as part of the X-variable, i.e. they are part of the random effect specification:

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[125] The same argument holds for z_{i1}^g as the g-th element from Z_{i1} and γ_τ^g the g-th element from γ_τ

[126] The correlation coefficient for publications and citations in our dataset is 0.77.

Rank. Researchers up for promotion are expected to have a higher motivation to provide research effort. Thus, in lower ranks, researchers should have more incentives to put in effort to get promotion. On the other hand, the higher ranks also have a strong incentive to put in effort in order to "prove their rank". In addition, having a more advanced rank may influence the way research is done. E.g. a full professor may have access to research assistants, may have a more extensive research network as well as an established reputation that allows for a more steady stream of output compared to more junior professors. Note that since past research output is taken into account when hiring and promoting, it is likely that current performance will increase the probability of getting a higher rank. To take this endogeneity (at least partly) into account, we lag the rank indicators by one period[127].

Seniority in rank. The variable seniority in rank should capture increasing pressure to provide effort, the longer a researcher is in his current rank (since the more likely she is to be up for promotion). We might expect a non-linearity: once a researcher is far beyond the expected seniority (typically two years), this might reflect a structurally reduced probability to get promotion. Also, the more senior, the higher is the wage and thus the smaller is the marginal benefit from increasing wage with rank. Especially in the end rank (full professor) seniority in rank looses its specific function and will correlate with age.

Head of a research unit. Heading a research lab may boost someone's output by having access to resources for research as well as being involved in more projects with the possibility of claiming coauthorship. Conversely, a prolific researcher may find that such duties hamper her from spending time on doing the

[127] For researchers who became a professor before 1992 (the first period of observation of our data, which covers 1992-2001) we observe the rank they had in 1991 so the one-period lagged rank variable can be assigned. For researchers entering in or after 1992 we do not have information on their rank in the year prior to entry. For these researchers we set the lagged rank variable in the first period of observation equal to "other rank", i.e. not one of the four main ranks. We consider this a fair assumption since these would typically be junior faculty who were active as post-docs before becoming a professor. Note that a missing value would completely remove those individuals from the dataset: due to the set-up of the CRE model, where *all* lagged rank variables enter the individual's yearly output function, a missing value for one of them would show up in every year, effectively removing the individual from the panel. An analogous comment applies to the definition of the lagged variables for funding and for head of unit status.

actual research. Given that high performers are more likely to become heads of unit, there is an issue of endogeneity, so we lag this variable by one period.

Project funding. Someone's publication record is expected to benefit from having access to additional research funds since they represent additional resources. Especially the Type I funding involve serious amounts of research funding. Since research performance is typically taken up as a criterion to judge research proposals, we lag this variable by one period.

Number of coauthors. We include a researcher's number of coauthors in every year in the model as a way to capture a researcher's collaborative style. Scientists that cooperate intensely with colleagues are expected to be more prolific than their peers who work in more solitary manner.

Teaching load. The inclusion of actual teaching load should be able to correct for the lost time for research when having to teach students. Therefore, we expect a negative impact of teaching load on research output. Due to self-selection of professors with an unobserved preference for teaching vis-à-vis research, controlling for such unobserved individual heterogeneity may reduce the effect.

The following characteristics are taken up as part of the Z-variable:

Gender. Previous research has repeatedly identified a productivity gap in the favor of male researchers.

Age and career age. A higher (biological) age may be beneficial for performance, given that it takes time and experience to build an advantage, although we expect a decreasing effect with time. We also include seniority as professor (frequently referred to as career age). This variable might be important beyond the seniority in rank in terms of the incentive to provide effort, since wages received by professors in Belgium are not only determined by rank, but also, and strongly, by seniority as professor.

Entry cohort. To disentangle age from cohort effects, we also include dummies for entry into the sample. The most important cohort effect seems to be a marked increase in hiring by the KU Leuven in 1992[128], for which we include a dummy variable.

Time. Apart from entry cohort effects, we include calendar year dummies in our model to control for trends such as increased publication pressure.

Discipline. All existing studies indicate the importance of controlling for scientific discipline idiosyncrasies.

Faculty membership. This allows capturing the influence of organizational structure and strategy to promote and provide incentives for research, to the extent that these units are responsible for developing a good research environment. It also allows correcting for the impact of spillovers from the quality or prestige of the group to which the researcher belongs.

Full-time versus part-time. Whether a professor holds a full-time position at the university has obvious implications for available research time and more generally captures whether a professor is expected to do any research at all. Part time appointments, mostly occurring at the engineering faculty in our sample, are typically for people from industry who are hired and evaluated on teaching rather than research.

With respect to the impact of these variables at different points in the distribution we expect for all of the observed characteristics mentioned above that they have a smaller impact at the top of the distribution than at the bottom. We hypothesize that the individual effect primarily captures the researcher's talent and that this is the predominant "key success factor" in the upper tail of the productivity distribution where it dwarfs the effect of variables like age, gender, funding, teaching load, etc. Conversely, these observed characteristics are expected to manifest themselves more clearly at the bottom end of the distribution where the endowments in terms of research talent may be expected to be more modest. Alternatively, it may be the case that variables like research funding may no longer act as high-powered incentives at the top of the distribution. For example, for an established star scientist yet another research grant is unlikely to represent a major impulse to increase

[128] This peak in hiring corresponds mainly to a growing number of retiring faculty that needed to be replaced.

her output even further. In other words, also the loss of incentives power at the top may explain a declining impact of the observables.

4.4 Empirical results

4.4.1 Regression results

Quantity

The cross-sectional results are reported in table 4.6. Estimates for five quantiles[129] are shown together with, in the final column, the results of a zero-inflated negative binomial model explaining average publication output[130], as a benchmark for the quantile estimates. We formally test the difference of parameters across quantiles in section 2. The panel-data results are reported in table 4.7[131]. Again, estimates for five quantiles are shown[132] together with the results of a random effects negative binomial model[133] explaining average publication output. The specification for the panel-data model follows expression (4.2). The specification for the cross-sectional model is similar, but excludes the term $\sum_{t=1}^{T} X'_{it}\lambda^t_\tau$. The discussion

[129] Our choice of quantiles follows the one commonly made in the field of quantile regression. Other quantiles naturally would lead to different parameter estimates. However, we do not expect this to alter our conclusions.

[130] Note that the coefficients in this model cannot be interpreted as marginal effects. The reported parameters allow to judge the significance and the direction of the effect on the average number of publications per researcher and per year. The magnitude of the parameters in the zero-inflated negative binomial model should not be directly compared to the quantile regression parameters since the latter show the marginal effect on the respective conditional quantiles.

[131] The unobserved heterogeneity parameters λ^t are not reported. The estimates are available from the authors on request. The role of these parameters is discussed further in section 4.4.2 where we test their joint significance.

[132] The parameters reported here are based on 380 bootstraps and 10 jittered samples for each quantile, accounting for 380x5x10=19,000 regressions. A robustness check using 50 jittered samples for each quantile (instead of 10) shows that the point estimates are very robust.

[133] In the random effects negative binomial model the dispersion varies randomly across researchers such that the inverse of one plus the dispersion follows a Beta(r,s) distribution. Both r and s are significantly different from zero. A likelihood ratio test that compares the negative binomial panel estimator with the pooled estimator (i.e. the negative binomial estimator with a constant dispersion across researchers), strongly favors the panel data estimator.

of the parameters focuses on the comparison between the cross-sectional and the panel-data results for the quantile regressions.

Age. Support for an age effect is very limited. We find a small positive effect in the 90% quantile in both the cross-sectional and panel estimates. The positive age effect at the 10% quantile for the cross-sectional model is not confirmed in the panel-data results.

Career age. The models offer little or no evidence for any influence of career age: the marginally significant and negative effect in the lower quantiles of the cross-sectional model is not robust in the panel-data results.

Seniority in rank. The panel estimates show a significant negative influence on publication output with a decreasing effect higher up in the distribution, which disappears at the very top in the 90% quantile. Seniority in rank has no effect in the cross-sectional specification.

Rank. The three junior ranks are less productive than the most senior rank (full professor, the base category) with the productivity differential decreasing with rank. The difference between ranks is less outspoken in the panel-data model than in the cross-sectional model, especially between rank 3 (professor) and the most senior rank (full professor, the base category). Further, in both models the productivity differential between ranks becomes smaller the higher up we look in the distribution.

Head of a research unit. Heading a research unit has a positive impact on publication output but in the cross-sectional model the effect disappears for the upper half of the distribution. In the panel model, the effect remains present throughout the whole distribution, although it is clearly smaller in the 75% and 90% quantiles.

Project funding. Having access to project funding is positively related to research output, as expected. However, for the big type I funding it is mainly the lower quantiles that benefit. Similarly, the more modest type II research grants boost the output in the lower quantiles but this type of funding also makes the very prolific researchers even more productive. The effects of funding are comparable in both models.

Number of coauthors. The number of coauthors shows up as an significant control variable in both models, with a positive effect on output, although the magnitude is small.

Teaching load. The cross-sectional estimates show a small but significant negative impact on output, mainly for the lower quantiles. The panel data model shows a different picture: here we find a negative, albeit small, impact only at the top of the distribution (75% and 90% quantile). We attribute this difference to unobserved heterogeneity, with professors having an affinity for teaching likely to engage more in such activities.

Gender. There is evidence of a gender effect with male researchers more productive than their female colleagues. It is interesting to see the irregularity of the gender effect along the distribution: while absent for the 10% quantile, it is strongest for the moderately active researchers (25% quantile) and then decreases gradually for the higher quantiles, but remains significant up to the very top of the distribution (90% quantile). The gender effect in the panel-data model is very robust compared to the one in the cross-sectional model, as expected, since we did not endogenize this variable.

Full-time versus part-time. The control for being full-time at the university is very significant, as expected. For both models, the highest value appears in the 10% quantile, which confirms the intuition that being full-time primarily explains whether a researcher is engaged in research at all.

Entry cohort. Being part of the cohort that entered professorship in or after 1992 has a negative impact on publication output but only for moderately productive researchers (25% and 50% quantile in the panel-data results). The cross-sectional model offers no support for an entry cohort effect.

Time (not reported in the table). The dummies for calendar year, which may capture general trends like increased publication pressure, show a small and positive effect for the later years in the cross-sectional model. In the panel model they show a pattern, suggesting an increasing publication trend with the higher quantiles responding quicker than the lower quantiles: the 90% quantile shows a clealry significant positive coefficient from 1995 onwards (parameter value of 0.12 in 1995) with some of the lower quantiles joining in 1997. The magnitude of the effect tends to be greater for the lower quantiles than for the 90% quantile: we find, for example, parameter values of 0.99 and 0.66 for the 10% and 25% quantile respectively, versus 0.21 for the 90% quantile in 1999, all relative to 1992 as the base year[134].

Discipline and faculty membership (not reported in the table). Controlling for discipline and organizational unit is important, with similar estimates in both models[135].

To allow for an easy comparison of the cross-section and panel-data results, we show the quantile estimates for a selection of parameters from Tables 4.6 and 4.7 in Figure 4.2. The solid line indicates the point estimates for the five quantiles of the panel-data model with the dashed lines marking the 95% confidence interval. The dotted line are the cross-sectional estimates.

Quality

Since research quantity tends to correlate with research quality, we do not expect strong differences with the results in the previous section. Rather, we look for differences in the importance of productivity drivers along the quality distribution, as compared to the quantity distribution[136]. The cross-sectional results are reported in table 4.8. Again, the estimates for the five quantiles are shown together with, in the final column, the results of a zero-inflated negative binomial model. Table 4.9 shows the panel-data results[137]. Estimates for five quantiles are shown together with the results of a random effects negative binomial model[138] explaining

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134 All these estimates are significant at the 5% level.

135 The effect of discipline across quantiles depends on the discipline considered. For example, the productivity difference with the faculty of kinesiology & physical education (the base category) increases with quantile for the faculty of agriculture, while it decreases with quantile for the faculty of pharmacy.

136 When comparing quantity and quality results, we focus on signs and significance since it is questionable to compare the effect of a regressor on the number of publications with the effect on the number of citations, i.e. putting aside a purely mathematical interpretation, it is hard to argue that a variable that raises a given conditional quantile by 1.0 for publication output versus 0.5 for citation output has a ‘stronger impact on quantity than on quality’.

137 The unobserved heterogeneity parameters λ^t are not reported. The estimates are available from the authors on request.

138 In the random effects negative binomial model the dispersion varies randomly across researchers

average citation output. The cross-sectional and panel-data quantile estimates are compared in Figure 4.3.

Focusing on the panel-data results, the common findings for both productivity measures include:

- The absence of both a (biological) *age* effect and a life cycle effect (*career age*).
- The negative effect of *rank seniority* decreases from lower to higher quantiles. At the top of the distribution effect on publications or citations is no longer significant.
- The productivity difference between the three junior *ranks* and the full professor rank (in the favor of the latter) decreases from lower to higher rank and from lower to higher quantiles. For both the quantity and the quality model, the panel estimates are smaller than the cross-sectional estimates.
- The positive and decreasing effect of *heading a research lab*. At the top of the distribution the impact on publications or citations is no longer or only marginally significant.
- The positive effect of *type I "excellence" funding* decreases from lower to higher quantiles.
- The positive effect of the number of *coauthors* increases from lower to higher quantiles.
- The positive effect on productivity of *gender*, in favor of male researchers, is found for both the quantity and the quality model, where in both cases it remains absent for the extreme left side of the distribution (10% quantile).

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such that the inverse of one plus the dispersion follows a Beta(r,s) distribution. The s parameter is estimated significantly different from zero. A likelihood ratio test that compares the negative binomial panel estimator with the pooled estimator (i.e. the negative binomial estimator with a constant dispersion across researchers), strongly favors the panel data estimator.

- The positive effect of being employed *full-time* at the university decreases from lower to higher quantiles.
- The positive *time* trend.
- Similar patterns for the dummies for *discipline* and *organizational unit membership* across quantiles.

Based on the panel estimates, noteworthy differences between the quantity and quality regressions are:

- The positive effect of *type II funding* remains roughly constant from lower to higher quantiles of research quality while it was decreasing with quantile for research quantity. This indicates that small chunks of additional funding represent an upward shift in quality for researchers throughout the distribution, irrespective of their research talent. The reason this constant upward shift does not hold for type I funding may be due to the nature of this funding: while type II funds are more modest research grants most likely used by the researcher herself (to attend conferences, buy software, etc.), the large type I funds are awarded to large group of researchers and the impact on the personal output of the project's (co-)promoter[139] may be less pronounced.
- For the quality distribution, we find a negative effect of *teaching load* located at the lower end (10% and 25% quantile) and the top end (90% quantile), with the lower end "suffering" more from teaching duties. For the quantity distribution there is a very small negative effect at the top end only. This may indicate that teaching duties do not prohibit research as such, but rather that unproductive (or less able) researchers may have difficulties keeping up the quality of their research when facing time constraints.

[139] Recall that the funding dummies measure *promotorship* of a research project, not the mere involvement as a researcher in a project that was financed with those funds.

- The effect of *entry cohort* is differs: for both quantity and quality, we find a negative effect of being part of the most recent entry cohort, but only for the 25%-50% quantile (quantity) and the 25% quantile (quality). For research quality, there is an additional point in the distribution that shows a *positive* effect of the most recent entry cohort, namely at the very top of the distribution. This may again point to the role of ability: while the very able and recently entered researchers are able to deliver a quality surplus relative to older cohorts, they do not publish more than their more experienced colleagues. Conversely, those recent entrants with more modest research talent endowments (in the midst or lower half of the distribution) apparently face a disadvantage relative to their more experienced colleagues, which is translated into fewer publications, usually of lesser quality. In this part of the distribution, the smaller stock of research knowledge (or perhaps the lesser experience with the research process) for the younger cohort may not be compensated for by research talent.

4.4.2 Hypothesis testing

Here we discuss the results of various hypothesis tests for which we use the minimum-distance framework of Buchinsky (1998). We test the correlated random effects specification as well as the difference between parameters across quantiles.

Minimum-distance testing framework

Let r denote the number of quantiles we estimate: $\tau_1, ..., \tau_r$. For a given quantile τ, the parameter vectors β_τ, λ_τ^t , and γ_τ are defined as follows: $\beta_\tau = (\beta_{\tau 1}, ..., \beta_{\tau K})$, $\lambda_\tau^t = \left(\lambda_{\tau 1}^t, ..., \lambda_{\tau K}^t\right)'$, and $\gamma_\tau = (\gamma_{\tau 1}, ..., \gamma_{\tau G})'$, with K the number of variables in X_{it}, G the number of variables in Z_{it} and $L = T \times K$. The full parameter vector for a given quantile τ is given by $\delta_\tau = \left(\phi_\tau, \beta'_\tau, \lambda_\tau^{1\prime}, ..., \lambda_\tau^{T\prime}, \gamma'_\tau\right)'$. The parameter vector for all quantiles is denoted by $\delta = (\delta'_1, \delta'_2, ...\delta'_r)'$ where δ has dimension $r(K + L + G + 1) \times 1$. Let $\widehat{\delta}$ denote the estimator of δ and $\widehat{A}$ the estimated variance-covariance matrix of $\widehat{\delta}$, obtained via bootstrapping. This matrix allow us to test hypotheses involving parameters from different quantiles.

In the minimum-distance framework, the estimator of the restricted model is defined as (Buchinsky, 1998):

$$\widehat{\delta}^R = \arg\min \left(\widehat{\delta} - R\delta^R\right)' \widehat{A}^{-1} \left(\widehat{\delta} - R\delta^R\right)$$

where R is the restriction matrix, the precise form of which depends on the hypothesis under consideration. The detailed specification of the restriction matrix R for the tests in the following sections is given in Appendix 1. Since we only consider linear restrictions, $\widehat{\delta}^R$ can be written as $\widehat{\delta}^R = \left(R'\widehat{A}^{-1}R\right)^{-1} \left(R'\widehat{A}^{-1}\widehat{\delta}\right)$ with R, $\widehat{A}^{-1}$ and $\widehat{\delta}$ known. The asymptotic variance of $\widehat{\delta}^R$ is given by $var\left(\widehat{\delta}^R\right) = \left(R'\widehat{A}^{-1}R\right)^{-1}$.

The null hypothesis is formulated as $H_0 : \delta = R\delta^R$. Under H_0, the following test statistic has a limiting chi-squared distribution:

$$\left(\widehat{\delta} - R\delta^R\right)' \widehat{A}^{-1} \left(\widehat{\delta} - R\widehat{\delta}^R\right) \underset{H_0}{\longrightarrow} \chi^2_M$$

with M the number of restrictions i.e. $M = rows(R) - columns(R)$.

Test results

Test of correlated random effects

Here we test whether our approach of modeling the individual effect in terms of observables is valid. The null hypothesis states that the λ parameters are jointly equal to zero, $H_0 : \lambda^1_\tau = ... = \lambda^T_\tau = 0$, simultaneously for all τ with $\tau \in \{0.10, 0.25, 0.50, 0.75, 0.90\}$. The null hypothesis is strongly rejected with a p-value very close to zero.

Test of equality of individual parameters across quantiles

Here we test whether a certain variable has a differential effect across quantiles, informing us whether looking at quantiles really gives us additional information compared to regressions on the mean. For example, we test whether the gender effect has an equal effect across the five estimated quantiles, with $H_0 : \beta^{male}_{\tau=0.10} =$

$\beta^{male}_{\tau=0.25} = \beta^{male}_{\tau=0.50} = \beta^{male}_{\tau=0.75} = \beta^{male}_{\tau=0.90}$. The test results for the cross-sectional and the panel-data specification are reported in Table 4.10, for both quantity and quality of output. We report the χ^2-values and indicate the significance. These tests yield strong evidence that for most parameters the estimates vary over the five quantiles. The only exceptions are rank seniority (cross-sectional publications model) and teaching load (panel-data publications model). Naturally, pairwise comparisons of quantiles would show fewer significant differences than comparing the estimates of a given parameter across all quantiles[140], but overall we consider this as strong support for a quantile regression approach, compared to an analysis of mean productivity only.

4.5 Conclusions and further research

This paper has estimated the impact of various productivity drivers along the productivity distribution, both in terms of quantity and quality. To account for unobserved heterogeneity in the estimation of the conditional quantiles, we used a correlated random effects model, exploiting the panel nature of our dataset. We subjected the integer counts of publications and citations to a randomization approach to allow for quantile estimation.

We found strong support for our quantile regression approach vis-à-vis regressions on the conditional mean only, as indicated by the differential impact of most variables along the distribution. Further, we find support for the hypothesis that the top of the distribution is mainly driven by talent (or a loss of incentive power of the observed variables), as opposed to the lower end where the impact of other characteristics is more visible. The evidence is provided by the stronger impact of several observed variables on the lower quantiles versus a weaker (or even insignificant) effect on the higher quantiles. In both the quantity and the quality models, the effect of rank, seniority in rank, head of unit, big research grants[141]

[140] As noted above, we ackowledge that the choice of quantiles is somewhat arbitrary, and a different selection of quantiles may yield different results, but we do not expect this to have a substantial impact on our results.

[141] For the quantity model, also the impact of the smaller type II funding decreases with quantile.

and full-time position followed a monotonously decreasing pattern across the five estimated quantiles. A notable exception is the gender effect that, although also satisfying the decreasing impact towards the top end of the distribution, does not play any role at the extreme lower end. The role of entry cohort across quantiles is hard to pin down as a simple pattern.

As far as the comparison between the analyses for research quantity and research quality is concerned, we found several observed factors to have a very similar effect, viz. age & career age (no effect), rank & rank seniority, type I funding, head of unit, and the control variables (co-authors, fulltime position, discipline, time, faculty membership). Given the correlation between quantity and quality of research, this strengthens our confidence in the findings. The effects of small research funds, teaching load and entry cohort show a different pattern across the quantity versus quality distribution.

Although we caution against generalizations based on this study of a single university, we believe our findings are informative with respect to the management of scientists in research organizations. In particular, the results may instill the right expectations in administrators who implement incentive programs or make funding decisions. For example, our estimates indicate that a reduced teaching load for not very productive researchers in an attempt to "pull them on board" may not lead to the expected increase in publications.

With respect to funding, the results indicate that this tends to reduce output inequality between researchers: the positive effect of funding is generally larger for the lower quantiles than is observed at the top of the distribution. One must be careful not to interpret this as meaning that the less productive researchers are more apt in converting additional funding into publications or citations than more prolific researchers[142]: the estimates are conditional on the actual distribution of research funds. As Table 4.5 shows, this distribution is inegalitarian with the top

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For the quality model, type II funding follows a reverse U-shape although this precise pattern may depend on the choice of quantiles that are estimated.

142 In addition, a full evaluation of funding decisions on productivity should take into account their impact on all researchers part of the receiving research group, and not only on the (co-)promoters of the projects, as in the regressions presented here.

scientists getting most of the funding, so there likely is an issue of diminishing returns. Nevertheless, the results show that research money flowing to the lower half of the distribution may be well spent, cautioning against an extreme selectivity in awarding research funds.

4.6 Tables & Figures

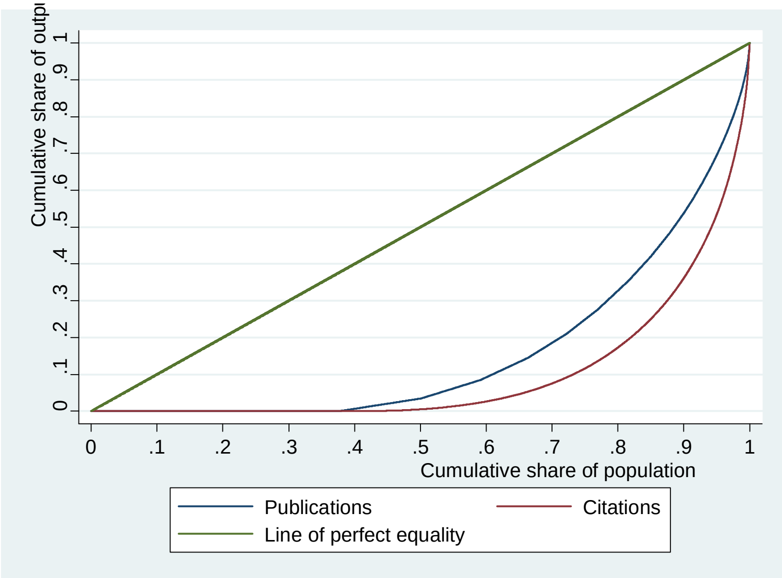

Figure 4.1: Lorenz curves for yearly research output

Table 4.1: Distribution of researchers over organizational units

Organizational Unit	Freq.	Percent
Group Exact Sciences	483	46.9
Faculty of Science	192	18.6
Faculty of Engineering	214	20.8
Faculty of Applied Bioscience and Engineering	77	7.5
Group Biomedical Sciences	547	53.1
Faculty of Medicine	460	44.7
Faculty of Pharmaceutical Sciences	36	3.5
Faculty of Physical Education & Kinesiology	51	5.0
Total	1030*	100.0

* Six people switched between groups and/or faculties in the period 1992-2001 and are not shown in this table.

Table 4.2: Distribution of researchers over disciplines

Main Discipline	Freq.	Percent
None (inactive researchers)	222	21.5
Clinical and Experimental Medicine II (Non-internal Medicine Specialties)	190	18.4
Clinical and Experimental Medicine I (General & Internal Medicine)	157	15.2
Biosciences (General, Cellular & Subcellular Biology; Genetics)	91	8.8
Chemistry	86	8.3
Engineering	72	7.0
Physics	65	6.3
Agriculture & environment	36	3.5
Biology (Organismic & Supraorganismic level)	31	3.0
Biomedical research	26	2.5
Mathematics	26	2.5
Geosciences & space sciences	19	1.8
Neuroscience & behavior	13	1.3
Total	1034*	100.0

* Two researchers had a tie in terms of their number of publications for two or more disciplines and are not shown.

Table 4.3: Research output (yearly averages)

Variable	Mean
Publications per author	3.3
	(5.1)
Coauthors per publication	4.7
	(3.7)
Citations per publication	3.0
	(4.2)
Impact measure per publication	3.2
	(2.4)
(co-)Promoted PhDs	0.3
	(0.5)
Number of researchers	1036

Standard deviations in brackets

Table 4.4: Percentiles for publication output, by discipline (yearly averages)

	Percentiles				
Main discipline	10%	25%	50%	75%	90%
Agriculture and Environment	0.0	0.1	1.9	5.2	8.8
Biosciences	0.6	1.6	4.3	8.4	14.3
Chemistry	0.0	0.8	3.7	8.0	13.3
Engineering	0.0	0.0	1.2	3.0	5.6
Geosciences and Space Sciences	0.0	0.1	1.0	4.0	6.8
Mathematics	0.0	0.1	1.2	2.9	4.8
Clinical and Experimental Medicine I	0.0	1.4	4.0	7.1	12.1
Clinical and Experimental Medicine II	0.0	0.2	2.0	4.8	8.4
Neuroscience and Behavior	0.1	0.3	1.5	4.5	7.7
Physics	0.0	1.0	3.5	7.6	13.3
Biomedical Research	0.1	0.3	2.2	6.8	12.2
Biology	0.2	0.5	2.4	6.0	10.4
Average	0.1	0.5	2.4	5.7	9.8

Since a researcher's main discipline can only be determined if she has any output, this table only includes the researchers with at least one publication in 1992-2001 (N=814)

Table 4.5: Individual and career-related variables by percentile of publication output

Variable	Whole sample		Inactive researchers	Active researchers Publication output percentiles					
				<10%	10%-25%	25%-50%	50%-75%	75%-90%	>90%
	mean	s.d.	mean	mean	mean	mean	mean	mean	mean
Male	0.89	0.32	0.86	0.79	0.84	0.88	0.91	0.93	0.95
Age	47.74	8.98	50.95	46.52	48.67	46.48	46.41	46.09	47.10
% age cohort 1 (age<40)	0.25	0.38	0.16	0.28	0.22	0.28	0.28	0.29	0.23
% age cohort 2 (40≤age<50)	0.32	0.36	0.26	0.28	0.28	0.33	0.33	0.35	0.37
% age cohort 3 (50≤age<60)	0.31	0.37	0.35	0.41	0.35	0.29	0.31	0.28	0.32
% age cohort 4 (60<age)	0.13	0.29	0.24	0.04	0.15	0.09	0.08	0.09	0.08
Entry cohort*									
% entry cohort 1 (1955-1980)	0.19	0.39	0.18	0.04	0.18	0.17	0.18	0.19	0.24
% entry cohort 2 (1981-1988)	0.19	0.39	0.14	0.07	0.15	0.18	0.22	0.25	0.31
% entry cohort 3 (1989-1991)	0.24	0.43	0.23	0.44	0.28	0.27	0.26	0.27	0.20
% entry cohort 4 (1992-...)	0.38	0.49	0.45	0.44	0.38	0.37	0.34	0.30	0.24
Years of employment in 1992-2001	7.51	2.88	6.48	8.45	8.07	7.89	8.19	8.42	8.61
Fulltime at university	0.80	0.38	0.47	0.90	0.81	0.87	0.92	0.96	0.98
Rank**									
% rank 1 (junior)	0.24	0.03	0.37	0.21	0.35	0.28	0.18	0.14	0.06
% rank 2	0.22	0.02	0.28	0.23	0.24	0.25	0.20	0.17	0.08
% rank 3	0.16	0.03	0.13	0.14	0.15	0.18	0.18	0.18	0.14
% rank 4 (senior)	0.25	0.02	0.14	0.08	0.16	0.19	0.26	0.35	0.55
Rank seniority***	5.71	6.69	5.64	5.40	5.78	5.24	5.44	5.79	7.45
rank 1 (junior)	2.41	2.26	3.01	3.47	3.01	2.13	1.97	1.68	1.44
rank 2	3.10	2.68	3.75	3.53	3.59	3.30	2.59	2.12	1.75
rank 3	4.25	5.00	5.77	0.75	6.54	4.85	3.20	3.15	2.51
rank 4 (senior)	12.26	8.51	16.97	18.67	14.03	12.80	11.63	10.91	10.61
Teaching load (year-hours)	4.18	4.09	3.38	2.61	3.63	4.34	4.51	4.37	4.80
rank 1 (junior)	1.49	1.77	1.72	0.86	1.42	1.54	1.26	1.25	1.04
rank 2	3.08	3.11	2.81	2.26	2.60	3.55	3.22	2.64	2.75
rank 3	4.95	3.67	4.81	3.01	5.86	5.87	4.96	3.83	3.10
rank 4 (senior)	7.96	4.40	8.31	7.56	7.95	8.95	8.67	7.56	6.45
Project funding									
% with type I funding	0.09	0.24	0.00	0.08	0.04	0.08	0.13	0.17	0.21
as promoter	0.03	0.13	0.00	0.00	0.00	0.01	0.03	0.05	0.09
as co-promoter	0.07	0.20	0.00	0.08	0.04	0.07	0.11	0.13	0.12
% with type II funding	0.11	0.23	0.02	0.10	0.07	0.10	0.14	0.17	0.22
as promoter	0.06	0.17	0.01	0.10	0.03	0.06	0.08	0.09	0.11
as co-promoter	0.05	0.15	0.01	0.00	0.04	0.04	0.06	0.08	0.12
Number of researchers	1036		222	814					

* For 44 researchers this information is missing.
** Only the four main ranks shown. People may be in other ranks which are of lesser concern here (e.g. 'jury member PhD') or may combine one of these other ranks with one of the main ranks.
*** This is the expected rank seniority for someone in a given rank; not the total number of years scientists tend to spend in each rank.

Table 4.6: Cross-sectional estimation results, publication data

	Quantile regressions					Zero-inflated
	10%	25%	50%	75%	90%	negative binomial
age	0.14**	0.01	0.02	0.02	0.03*	0.01
	(2.81)	(0.11)	(0.31)	(0.79)	(1.68)	(0.17)
age squared	-0.00**	-0.00	-0.00	-0.00	-0.00**	-0.00
	(-3.30)	(-0.47)	(-0.86)	(-1.57)	(-2.51)	(-0.47)
career age	-0.03*	-0.02*	0.00	0.00	0.00	0.00
	(-1.69)	(-1.65)	(0.13)	(0.37)	(0.65)	(0.11)
seniority in rank	0.01	0.00	-0.00	0.00	0.00	-0.00
	(0.64)	(0.11)	(-0.08)	(0.31)	(1.17)	(-0.31)
rank						
rank 1 in t-1	-1.18**	-0.94**	-0.75**	-0.53**	-0.38**	-0.61**
	(-10.12)	(-14.03)	(-5.42)	(-5.31)	(-7.30)	(-5.97)
rank 2 in t-1	-0.73**	-0.68**	-0.59**	-0.36**	-0.23**	-0.38**
	(-2.94)	(-7.28)	(-5.94)	(-12.98)	(-11.06)	(-5.08)
rank 3 in t-1	-0.33*	-0.35**	-0.37**	-0.24**	-0.12**	-0.22**
	(-1.84)	(-2.77)	(-3.66)	(-6.77)	(-9.65)	(-3.30)
other rank in t-1	-0.78**	-0.87**	-0.69**	-0.44**	-0.26**	-0.42**
	(-7.19)	(-7.02)	(-11.68)	(-6.19)	(-6.99)	(-5.15)
head of unit in t-1	0.51**	0.35**	0.17**	0.07	0.04	0.10**
	(3.23)	(3.50)	(2.10)	(1.35)	(0.50)	(2.02)
project funding						
type I funding in t-1	1.14**	0.63**	0.26**	0.14**	0.03	0.17**
	(10.69)	(8.73)	(4.02)	(10.87)	(0.73)	(2.73)
type II funding in t-1	0.77**	0.56**	0.27**	0.22**	0.17**	0.12*
	(9.08)	(26.45)	(22.09)	(7.94)	(15.16)	(1.82)
nr of co-authors	0.01**	0.02**	0.02**	0.03**	0.03**	0.02**
	(3.17)	(3.97)	(9.51)	(17.55)	(23.12)	(8.03)
teaching load	-0.07**	-0.03**	-0.02**	-0.01**	-0.01**	-0.03**
	(-7.17)	(-4.46)	(-4.95)	(-3.90)	(-2.01)	(-2.49)
male	0.91	0.57**	0.37**	0.24**	0.17**	0.21
	(1.31)	(3.17)	(5.30)	(14.75)	(3.71)	(1.56)
fulltime	1.28**	0.74**	0.88**	0.70**	0.57**	0.43**
	(4.77)	(7.70)	(10.55)	(8.31)	(17.68)	(3.20)
entry $\geq$ 1992	-0.07	-0.11	-0.14*	-0.09	-0.02	-0.06
	(-0.59)	(-1.45)	(-1.72)	(-1.54)	(-0.17)	(-0.64)
year dummies			*included*			*included*
main discipline			*included*			*included*
faculty membership			*included*			*included*
Observations			7,062			7,062

t-statistics in parentheses. The parameters for the quantile regressions are based on 10 jittered samples, the standard errors are calculated using 380 clustered bootstrap samples (clustering by by individual).
* $p<0.10$, ** $p<0.05$

Table 4.7: Panel-data estimation results, publication data

	Quantile regressions					Random effects
	10%	25%	50%	75%	90%	negative binomial
age	0.10	0.02	0.03	0.03	0.03**	0.08**
	(1.64)	(0.24)	(0.37)	(0.96)	(2.62)	(3.96)
age squared	-0.00**	-0.00	-0.00	-0.00	-0.00**	-0.00**
	(-2.16)	(-0.62)	(-0.76)	(-1.57)	(-4.06)	(-6.07)
career age	-0.02	-0.03	-0.01	0.00	0.00	0.04**
	(-0.68)	(-1.61)	(-0.39)	(0.02)	(0.88)	(5.24)
seniority in rank	-0.08**	-0.05**	-0.04**	-0.02**	-0.01	-0.01**
	(-3.26)	(-3.76)	(-3.36)	(-2.71)	(-0.90)	(-2.52)
rank						
rank 1 in t-1	-0.78**	-0.84**	-0.61**	-0.39**	-0.21**	-0.25**
	(-6.22)	(-5.46)	(-4.23)	(-3.12)	(-3.43)	(-4.35)
rank 2 in t-1	-0.28	-0.40**	-0.45**	-0.21**	-0.09**	-0.13**
	(-1.23)	(-3.64)	(-12.25)	(-3.44)	(-5.80)	(-2.81)
rank 3 in t-1	-0.02	-0.11	-0.20**	-0.10	-0.01	-0.11**
	(-0.17)	(-1.49)	(-5.45)	(-1.32)	(-1.27)	(-2.66)
other rank in t-1	-0.59**	-0.77**	-0.57**	-0.28**	-0.13**	-0.25**
	(-5.13)	(-10.91)	(-6.16)	(-2.17)	(-3.42)	(-4.55)
head of unit in t-1	0.48**	0.37**	0.21*	0.07*	0.08*	0.07**
	(4.12)	(4.12)	(1.96)	(1.93)	(1.77)	(2.15)
project funding						
type I funding in t-1	0.76**	0.54**	0.20*	0.12**	0.03	0.09**
	(6.20)	(7.83)	(1.80)	(3.42)	(0.61)	(2.63)
type II funding in t-1	0.55**	0.39**	0.24**	0.18**	0.17**	0.09**
	(11.77)	(14.60)	(8.58)	(5.25)	(7.53)	(3.29)
nr of co-authors	0.01**	0.02**	0.02**	0.03**	0.03**	0.00**
	(2.13)	(7.80)	(13.66)	(44.16)	(20.06)	(28.70)
teaching load	-0.05	-0.02	-0.01	-0.01**	-0.01**	-0.01
	(-1.36)	(-1.34)	(-1.01)	(-2.43)	(-4.33)	(-1.64)
male	0.66	0.58**	0.34**	0.25**	0.18**	0.36**
	(0.78)	(3.50)	(2.34)	(15.21)	(2.93)	(3.41)
fulltime	1.27**	0.67**	0.81**	0.68**	0.61**	0.39**
	(4.04)	(11.80)	(13.07)	(6.75)	(17.42)	(5.69)
entry $\geq$ 1992	-0.30	-0.40**	-0.21**	-0.06	0.10	-0.17*
	(-1.12)	(-3.82)	(-2.03)	(-0.74)	(0.76)	(-1.76)
year dummies			*included*			*included*
main discipline			*included*			*included*
faculty membership			*included*			*included*
N			7,062			7,062

t-statistics in parentheses. The parameters for the quantile regressions are based on 10 jittered samples, the standard errors are calculated using 380 clustered bootstrap samples (clustering by by individual).
* $p<0.10$, ** $p<0.05$

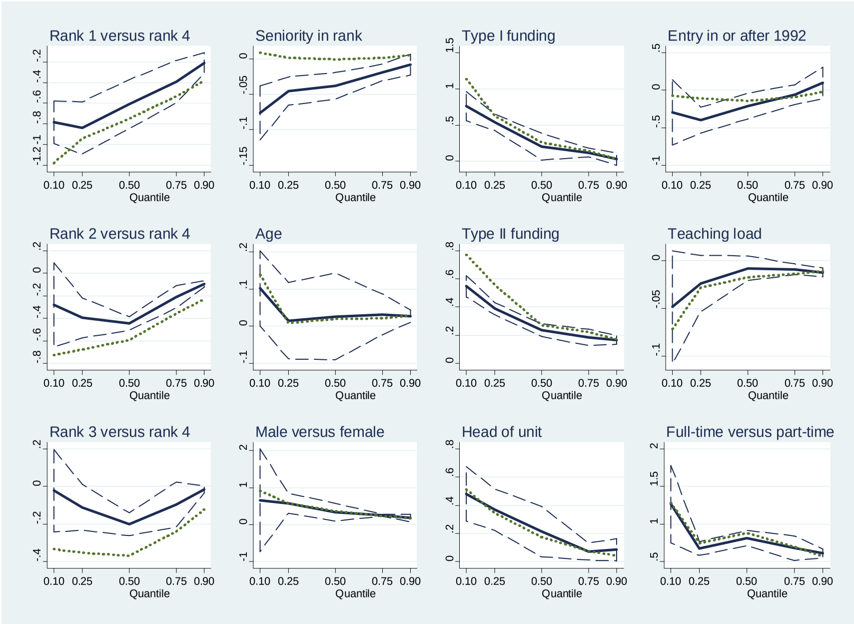

Figure 4.2: Estimates for publication data (Solid = Panel, Dashed = Panel 95% CI, Dotted=Cross-section)

Table 4.8: Cross-sectional estimation results, citation data

	Quantile regressions					Zero-inflated
	10%	25%	50%	75%	90%	negative binomial
age	0.16*	-0.06	-0.01	-0.03	-0.02	-0.06*
	(1.87)	(-0.59)	(-0.12)	(-0.33)	(-0.67)	(-1.79)
age squared	-0.00**	0.00	-0.00	-0.00	-0.00	0.00
	(-2.20)	(0.07)	(-0.44)	(-0.23)	(-1.17)	(0.97)
career age	-0.03**	-0.02	-0.00	0.01	0.01	-0.00
	(-2.12)	(-0.95)	(-0.31)	(0.47)	(1.17)	(-0.29)
seniority in rank	-0.01	-0.01	0.01	-0.00	0.01	0.00
	(-0.44)	(-0.35)	(0.47)	(-0.21)	(1.11)	(0.23)
rank						
rank 1 in t-1	-1.61**	-1.49**	-1.07**	-0.53**	-0.35**	-0.30**
	(-7.59)	(-6.09)	(-6.55)	(-3.10)	(-21.77)	(-2.67)
rank 2 in t-1	-1.19**	-1.08**	-0.89**	-0.46**	-0.26**	-0.21**
	(-5.54)	(-6.67)	(-7.08)	(-8.32)	(-2.37)	(-2.31)
rank 3 in t-1	-0.61**	-0.44**	-0.50**	-0.34**	-0.17**	-0.11
	(-2.45)	(-2.48)	(-3.23)	(-7.11)	(-9.93)	(-1.31)
other rank in t-1	-1.49**	-1.46**	-0.99**	-0.58**	-0.33**	-0.27**
	(-8.92)	(-5.80)	(-23.87)	(-5.66)	(-7.44)	(-2.70)
head of unit in t-1	0.60**	0.53**	0.27**	0.13*	0.07	0.06
	(5.01)	(3.18)	(3.54)	(1.95)	(0.79)	(0.86)
project funding						
type I funding in t-1	1.80**	1.13**	0.73**	0.51**	0.30**	0.40**
	(17.99)	(11.50)	(5.81)	(6.22)	(3.13)	(5.90)
type II funding in t-1	1.17**	0.94**	0.58**	0.55**	0.45**	0.20**
	(6.74)	(6.55)	(12.35)	(11.15)	(10.07)	(3.42)
nr of co-authors	0.01**	0.02**	0.03**	0.03**	0.04**	0.02**
	(3.09)	(3.63)	(9.26)	(12.56)	(12.89)	(7.74)
teaching load	-0.09**	-0.06**	-0.04**	-0.03**	-0.02**	-0.02
	(-6.03)	(-3.90)	(-6.35)	(-14.61)	(-2.01)	(-1.09)
male	1.21	1.05**	0.81**	0.35**	0.12**	0.14
	(1.35)	(4.75)	(4.32)	(6.04)	(2.91)	(1.20)
fulltime	1.20**	1.10**	1.17**	0.90**	0.53**	0.02
	(5.03)	(13.14)	(5.48)	(8.94)	(9.53)	(0.14)
entry $\geq$ 1992	0.07	-0.11	-0.15	-0.25**	-0.09**	-0.13
	(0.26)	(-0.87)	(-1.35)	(-2.36)	(-2.00)	(-1.48)
year dummies			*included*			*included*
main discipline			*included*			*included*
faculty membership			*included*			*included*
Observations			7,062			7,062

t-statistics in parentheses. The parameters for the quantile regressions are based on 10 jittered samples, the standard errors are calculated using 380 clustered bootstrap samples (clustering by by individual).
* $p<0.10$, ** $p<0.05$

Table 4.9: Panel-data estimation results, citation data

	Quantile regressions					Random effects
	10%	25%	50%	75%	90%	negative binomial
age	0.11	-0.08	0.01	-0.02	-0.01	0.03
	(1.57)	(-0.95)	(0.05)	(-0.23)	(-0.18)	(1.16)
age squared	-0.00**	0.00	-0.00	-0.00	-0.00	-0.00**
	(-2.05)	(0.38)	(-0.62)	(-0.30)	(-0.63)	(-2.72)
career age	-0.01	-0.04	-0.02	0.00	0.00	0.01
	(-0.24)	(-0.96)	(-1.03)	(0.03)	(0.30)	(1.45)
seniority in rank	-0.11**	-0.09**	-0.06**	-0.04**	-0.01	-0.00
	(-2.62)	(-3.74)	(-2.46)	(-20.79)	(-1.03)	(-0.10)
rank						
rank 1 in t-1	-1.28**	-1.11**	-0.76**	-0.37**	-0.31**	-0.56**
	(-4.57)	(-3.02)	(-4.45)	(-2.15)	(-3.99)	(-7.00)
rank 2 in t-1	-0.62**	-0.62**	-0.53**	-0.29**	-0.20**	-0.36**
	(-3.15)	(-2.26)	(-16.90)	(-2.88)	(-2.22)	(-5.56)
rank 3 in t-1	-0.43**	-0.06	-0.26*	-0.23**	-0.15**	-0.22**
	(-2.45)	(-0.47)	(-1.92)	(-2.68)	(-11.10)	(-3.89)
other rank in t-1	-1.34**	-1.23**	-0.77**	-0.47**	-0.34**	-0.53**
	(-4.68)	(-7.28)	(-11.44)	(-2.89)	(-5.00)	(-6.69)
head of unit in t-1	0.78**	0.67**	0.32**	0.14**	0.05	0.18**
	(3.30)	(4.22)	(2.25)	(3.51)	(0.96)	(3.98)
project funding						
type I funding in t-1	1.20**	1.06**	0.64**	0.40**	0.30**	0.41**
	(10.28)	(5.22)	(4.04)	(3.08)	(2.60)	(7.58)
type II funding in t-1	0.50**	0.76**	0.54**	0.52**	0.45**	0.26**
	(2.73)	(4.41)	(9.07)	(13.30)	(6.53)	(6.16)
nr of co-authors	0.02**	0.02**	0.03**	0.03**	0.04**	0.00**
	(2.48)	(8.31)	(9.61)	(20.90)	(27.07)	(26.39)
teaching load	-0.07**	-0.06**	-0.02	-0.01	-0.02**	-0.03**
	(-2.64)	(-2.25)	(-1.02)	(-1.22)	(-3.03)	(-4.19)
male	1.03	1.19**	0.76**	0.35**	0.18**	0.47**
	(1.19)	(4.29)	(2.94)	(2.83)	(2.31)	(5.77)
fulltime	1.20**	1.10**	1.15**	0.92**	0.55**	0.74**
	(6.14)	(9.59)	(5.95)	(13.78)	(8.35)	(9.02)
entry $\geq$ 1992	-0.36	-0.48**	-0.17	-0.10	0.16**	-0.25**
	(-0.73)	(-4.65)	(-1.12)	(-1.34)	(2.96)	(-3.55)
year dummies			*included*			*included*
main discipline			*included*			*included*
faculty membership			*included*			*included*
Observations			7,062			7,062

t-statistics in parentheses. The parameters for the quantile regressions are based on 10 jittered samples, the standard errors are calculated using 380 clustered bootstrap samples (clustering by by individual).
* $p<0.10$, ** $p<0.05$

Figure 4.3: Estimates for citation data (Solid = Panel, Dashed = Panel 95% CI, Dotted=Cross-section)

Table 4.10: Test of equality of individual parameters across quantiles (chi-squared values)

	Publications		Citations	
	cross-section	panel data	cross-section	panel data
age	7.64	5.36	21.43**	18.34**
age squared	11.59**	7.09	30.80**	26.50**
career age	43.37**	31.24**	40.29**	65.89**
seniority in rank	7.81*	113.67**	11.92**	103.25**
rank				
rank 1 in t-1	223.19**	32.45**	233.37**	116.60**
rank 2 in t-1	80.96**	204.38**	43.59**	45.53**
rank 3 in t-1	22.76**	93.50**	21.48**	12.39**
other rank in t-1	75.82**	97.69**	419.91**	228.51**
head of unit in t-1	409.46**	115.70**	211.04**	94.35**
project funding				
type I funding in t-1	488.44**	488.54**	741.94**	250.83**
type II funding in t-1	244.39**	136.41**	43.31**	17.71**
nr of co-authors	1,267.21**	96.18**	1,742.02**	117.95**
teaching load	69.02**	4.19	31.28**	35.09**
male	24.48**	86.68**	135.72**	118.56**
fulltime	17.64**	27.20**	179.55**	390.31**
entry $\geq$ 1992	5.18	123.02**	28.57**	173.39**

The variance-covariance matrix is calculated using bootstrapping. For the publication panel-data results, 2 out of 380 bootstraps were dropped due to outliers; for the other models 1 out of 380 bootstraps was dropped.
* $p<0.10$, ** $p<0.05$

4.A Appendix: Restriction matrices for hypothesis testing

Here we give the detailed specification of the restriction matrix R used in the hypothesis testing in section 2 of this chapter.

Test of correlated random effects

Test of $H_0 : \lambda_\tau^1 = ... = \lambda_\tau^T = 0$, $\forall\tau$.

We define

$$R = \left[I_{r\times r} \otimes \begin{bmatrix} I_{K\times K} & O_{K\times G} & O_{(K+L+G)\times 1} \\ O_{L\times K} & O_{L\times G} & \\ O_{G\times K} & I_{G\times G} & \\ O_{1\times(K+G)} & & 1 \end{bmatrix} \right]$$

with I the identity matrix, O a matrix of zeroes and $\otimes$ the Kronecker product, so that $M = rL$.

Test of equality of individual parameters across quantiles

We define

$$R = \begin{bmatrix} i_{r\times 1} & & O_{r\times r(K+L+G)} & & \\ O_{r(K+L+G)\times 1} & I_{rxr} \otimes & \begin{matrix} I_{(K+G-1)\times(K+G-1)} \\ O_{L\times(K+G-1)} \\ O_{1\times(K+L+G-1)} \end{matrix} & \begin{matrix} O_{(K+G-1)\times L} \\ I_{L\times L} \\ \end{matrix} & \begin{matrix} O_{(K+G-1)\times 1} \\ O_{L\times 1} \\ 1 \end{matrix} \end{bmatrix}$$

with i a matrix of ones[143], so that $M = r - 1$.

[143] This definition of R requires that the r parameters to be tested (one from each quantile) are the first r elements in δ. Therefore, δ is resorted prior to calculating the test statistic.

References

Abrevaya, J. & Dahl, C.M. 2005. *The effects of smoking and prenatal care on birth outcomes: evidence from quantile estimation on panel data.* Working Paper, Department of Economics, Purdue University.

Aghion, P. 2006. A primer on economic growth. *Bruegel Policy Brief*, 6: 1-8.

Allison, P. D., Long, J. S. & Krauze, T. K. 1982. Cumulative advantage and inequality in science. *American Sociological Review,* 47(5): 615-625.

Allison, P. D. & Stewart, J. A. 1974. Productivity differences among scientists: evidence for accumulative advantage. *American Sociological Review,* 39(4): 596-606.

Andersen, P. K. & Gill, R. D. 1982. Cox's regression model for counting processes: a large sample study. *Annals of Statistics*, 10: 1100-1120.

Atkinson, A.B., & Stiglitz, J.E. 1976. The design of tax structure: Direct versus indirect taxation. *Journal of Public Economics,* 6(1-2): 55-75.

Barr, N. 2004. Higher education funding. *Oxford Review of Economic Policy,* 20(2): 264-283.

Beck, M. & Fitzenberger, B. 2004. Changes in union membership over time: A panel analysis for West Germany. *Labour,* 18(3): 329-362.

Ben-Akiva, M. E. & Lerman, S. R. 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand.* Cambridge, Ma.: MIT Press.

Bergstrom, T. C., Roberts, J.A., Rubinfeld, D.L. & Shpiro, P. 1988. A test for efficiency in the supply of public education. *Journal of Public Economics,* 35: 289-307.

Bernier, C., Gill, W. & Hunt, R. 1975. Measures of Excellence of Engineering and Science Departments: A Chemical Engineering Example. *Chemical Engineering Education,* 194-197.

Berry, S. & Waldfogel, J. 1999. Free entry and social inefficiency in radio broadcasting. *RAND Journal of Economics,* 30 (3): 397-420.

Belgisch Staatsblad 2006. Koninklijk besluit tot wijziging van het KB/WIB 92, op het stuk van de voordelen van alle aard. 2006-02-17.

Ben-Akiva, M. E., & Lerman, S. R. 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge, Ma.: MIT Press.

Bierlaire, M., Bolduc, D. & McFadden, D. 2006. *The estimation of Generalized Extreme Value models from choice-based samples*. Report TRANSP-OR 060810. Transport and Mobility Laboratory, School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Federale de Lausanne.

Bird, R.M. 2005. *Evaluating public expenditures: Does it matter how they are financed?* Working Paper 0506. International Tax Program, Institute for International Business, Joseph L. Rotman School of Management, University of Toronto.

Bovenberg, A.L., & Jacobs, B. 2005. Redistribution and education subsidies are Siamese twins. *Journal of Public Economics,* 89: 2005-2035.

Buchinsky, M. 1994. Changes in the U.S. wage structure 1963-1987: Application of quantile regression. *Econometrica*, 62(2): 405-458.

Buchinsky, M. 1998. Recent advances in quantile regression: a practical guide for empirical research. *Journal of Human Resources*, 33: 88-126.

Cameron, A.C. & Trivedi, P. K. 1998. *Regression Analysis of Count Data.* Cambridge, U.K.: Cambridge University Press.

Cameron, S.V., Heckman, J.J. 2001. The Dynamics of Educational Attainment for Black, Hispanic and White Males. *Journal of Political Economy,* 109(3): 455-499.

Cantillon, B., Verbist, G., & Segal, I. 2005. *Student in de 21ste Eeuw. Studiefinanciering voor het hoger onderwijs in Vlaanderen*. Report for Onderwijskundig Beleids- en Praktijkgericht Wetenschappelijk Onderzoek (OBPWO), Ministerie van de Vlaamse Gemeenschap, Departement Onderwijs.

Chamberlain, G. 1982. Multivariate regression models for panel data. *Journal of Econometrics,* 18: 5-46.

Chamberlain, G. 1984. Panel data. In Z. Griliches a M.D. Intriligator (Eds.), *Handbook of Econometrics, Volume 2.* Amsterdam: North-Holland.

Cohn, E., Rhine, S. L. W. & Santos, M. C. 1989. Institutions of Higher-Education As Multi-Product Firms - Economies of Scale and Scope. *Review of Economics and Statistics,* 71 (2): 284-290.

Cole, S. & Cole, J. R. 1967. Scientific Output and Recognition: A Study in the Operation of the Reward System in Science. *American Sociological Review,* 32(3): 377-390.

Cole, S. 1970. Professional Standing and the Reception of Scientific Discoveries. *The American Journal of Sociology,* 76(2): 286-306.

Cole, S., Cole, J. R. 1973. *Social stratification in science*. Chicago: University of Chicago Press.

Cole, S. 1979. Age and scientific performance. *American Journal of Sociology,* 84(4): 958-977.

Cox, D. R. 1972. Regression Models and Life Tables. *Journal of the Royal Statistical Society,* B34: 187-220.

Cox, D. R. & Oakes, D. 1994. *Analysis of survival data*. London: Chapman and Hall.

Dasgupta, P. & David, P. A. 1994. Toward A New Economics of Science. *Research Policy,* 23(5): 487-521.

Deen, J., Jongbloed, B. & Vossensteyn, H. 2005. *Bekostigingstarieven in het hoger onderwijs. Een vergelijking tussen 7 landen*. Studie i.o.v. Ministerie van de Vlaamse Gemeenschap. Center for Higher Education and Policy Studies (CHEPS), Universiteit Twente.

De Fraja, G. & Iossa, E. 2002. Competition among Institutions and the Emergence of the Elite Institution. *Bulletin of Economic Research,* 54: 275-293.

Del Rey, E. 2001. Teaching versus Research: a model of state university competition. *Journal of Urban Economics,* 49: 356-373.

Diamond, P.E. & Mirrlees, J.A. 1971. Optimal taxation and public production: I. Production efficiency. *American Economic Review* 61: 8-27.

Diewert,W.E., Lawrence D.A. & Thompson, F. 1998. The Marginal Cost of Taxation and Regulation. In F. Thompson & M.T. Green (Eds.), *Handbook of Public Finance* (pp. 135-71). New York: Marcel Dekker.

Dixit, A. K. & Stiglitz, J. E. 1977. Monopolistic competition and optimum product diversity. *American Economic Review,* 67 (3): 297-308.

Dosi, G., Llerena, P. & Sylos-Labini, M. 2006. Science-technology industry links and the European paradox. *Research Policy*, to appear.

Dynarski, S.M. 2003. Does Aid Matter? Measuring the Effect of Student Aid on College Attendance and Completion. *American Economic Review,* 93(1): 279-288.

European Commission 2003. DG Education and Culture. Communication from the Commission. *Education & Training 2010. The Success of the Lisbon Strategy Hinges on Urgent Reforms*.

European Commission 2004. DG Education and Culture, Working Group E., Work Programme "Implementation of "Education & Training 2010". *Making The Best Use Of Resources*. *Progress Report.*

European Commission, 2006. Communication from the Commission to the Council and the European Parliament. COM(2006) 208 final. *Delivering on the modernization agenda for universities: education, research and innovation.*

Eurydice 2000. *Two decades of reform in higher education in Europe: 1980 onwards.* Eurydice, the Information Network on Education in Europe, http://www.eurydice.org.

Fox, M.F. 1983. Publication productivity among scientists: a critical review. *Social studies of science*, 13: 283-305.

Fox, J.T. 2007. Semiparametric estimation of multinomial discrete choice models using a subset of choices. *RAND Jornal of economics*, forthcoming.

Frenette, M. 2003. *Access to College and University : Does distance matter?* Report No.11F0019 201. Business and Labour Market Analysis, Statistics Canada.

Hausman, J., Leonard, G., & McFadden, D. 1995. A utility-consistent, combined discrete choice and count data model Assessing recreational use losses due to natural resource damage. *Journal of Public Economics,* 56: 1-30.

Hausman, J.A. & Leonard, G.K. 2002. The competitive effects of a new product introduction: a case study. *Journal of Industrial Economics*, 50, 237-263.

ISI Highly Cited database. 14 August 2007. From http://www.isihighlycited.com/.

Jacobs, B., & van der Ploeg, F. 2005. *Guide to Reform of Higher Education: A European Perspective.* CEPR Discussion Paper 5327.

Jobdienst KU Leuven 2006. *Overeenkomst voor tewerkstelling van studenten*. Retrieved April 24 2006, from http://www.kuleuven.be/jobstudent/contract.htm.

Jovanovic, B. 1982. Selection and the Evolution of Industry. *Econometrica,* 50(3): 649-670.

Kane, T.J. 1995. *Rising Public College Tuition and College Entry: How Well Do Public Subsidies Promote Access to College?* NBER Working Paper 5164.

Kelchtermans, S. & Veugelers, R. 2005. *Top research productivity and its persistence.* CEPR discussion paper 5415.

Kelchtermans, S. & Verboven, F. 2006. *Participation and Schooling in a Public System of Higher Education*. Discussion Paper 5690. 2006. Centre for Economic Policy Research (CEPR).

Koenker, R. & Bassett, G.W. 1978. Regression quantiles. *Econometrica*, 46: 33-50.

Koenker, R. 2004. Quantile regression for longitudinal data. *Journal of Multivariate Analysis,* 91: 74-89.

Koenker, R. & Hallock, K.F. 2001. Quantile regression. *Journal of Economic Perspectives*, 15: 143-156.

Lamarche, C. 2006. *Robust penalized quantile regression estimation for panel data.* Working Paper, University of Illinois at Urbana-Champaign.

Levin, S. G. S. & Stephan, P. 1991. Research productivity over the life cycle: Evidence for academic scientists. *American Economic Review,* 81(1): 114.

Long, J. S., Allison, P. D. & McGinnis, R. 1993. Rank Advancement in Academic Careers: Sex Differences and the Effects of Productivity. *American Sociological Review,* 58(5): 703-722.

Long, B. T. 2004. How have college decisions changed over time? An application of the conditional logistic choice model. *Journal of Econometrics,* 121(1-2): 271-296.

Lotka, A. J. 1926. The frequency distribution of scientific productivity. *Journal of the Washington Academy of Sciences,* 16: 317-323.

Maassen, P. 2000. *Models of Financing Higher Eduation in Europe.* A Background Paper Commissioned by the Nordic Council of Ministers for the Conference on "Financing Higher Education". Held in Reykjavík 3-4 April 2000. Center for Higher Education and Policy Studies (CHEPS), Universiteit Twente.

Machado, J.A.F. & Santos Silva, J.M.C. 2005. Quantiles for counts. *Journal of the American Statistical Association*, 100(472): 1226-1237.

Mairesse, J. & Turner, L. 2002. Individual Productivity Differences in Public Research : How important are non-individual determinants? An Econometric Study of French Physicists' publications and citations (1986-1997). *Cahiers de la MSE. Série Verte*. V02066.

Mankiw, N.G. & Whinston, M.D. 1986. Free entry and social inefficiency. *Rand Journal of Economics*, 17: 48-58.

McFadden, D. 1978. Modeling the Choice of Residential Location. In L. Lundqvist, F. Snickars & J. Weibul A.Karlqvist (Eds.), *Spatial Interaction Theory and Planning Models*. New York: North-Holland.

McFadden, D. 1981. Econometric Models of Probabilistic Choice. In C.F. Manski & D. McFadden (Eds.), *Structural Analysis of Discrete Data and Econometric Applications*. Cambridge, Ma.: MIT Press.

McFadden, D. & Train, K. 2000. Mixed MNL Models for Discrete Response. *Journal of Applied Econometrics,* 15(5): 447-470.

Merton, R. K. 1968. The Matthew Effect in Science. The reward and communication systems of science are considered. *Science,* 159: 56-63.

Merton, R. K. & Zuckerman, H. A. 1971. Patterns of Evaluation in Science: Institutionalization, Structure and Functions of the Referee System. *Minerva,* 9(1): 66-100.

Murphy, K.M. & Topel, R.H. 1985. Estimation and Inference in Two-Step Econometric Models. *Journal of Business & Economic Statistics,* 3(4): 370-379.

Nadeau B. & McNicoll, T. 2006. Europe's failing schools. Where the future is a dead end. *Newsweek*, 12 June 2006, 34-41.

Nevo, A. 2003. New products, quality changes, and welfare measures computed from estimated demand systems. *The Review of Economics and Statistics,* 85(2): 266-275.

OECD 2004. *Education at a Glance: OECD Indicators 2004*.

OECD 2006. *Education at a Glance: OECD Indicators 2006*.

Pakes, A. & Ericson, R. 1998. Empirical Implications of Alternative Models of Firm Dynamics. *Journal of Economic Theory,* 79(1): 1-46.

Perloff, J. M. & Ward, M. B. 2003. *Welfare, Market Power, and Price Effects of Product Diversity: Canned Juices*. Working paper.

Petrin, A. 2002. Quantifying the Benefits of New Products: The Case of the Minivan. *Journal of Political Economy*, 110:705-729.

Prentice, R. L., Williams, B. J. & Peterson, A.V. 1981. On the regression analysis of multivariate failure time data. *Biometrika,* 68(2): 373-379.

Rauber, M. & Ursprung, H.W. 2006. *Life cycle and cohort productivity in academic research: the continental European experience as exemplified by the case of Germany.* Working paper, University of Konstanz.

Riew, J. 1966. Economies of scale in high school operation. *Review of Economics and Statistics,* 48: 280-287.

Rouse, C. E. 1995. Democratization or diversion? The effect of community colleges on educational attainment. *Journal of Business Economics and Statistics*, 13(2): 217-224.

Shapiro, C. 1995. *Mergers with differentiated products*. Address before the American Bar Association, Washington DC, 11/9/1995.

Spence, M. 1976. Product differentiation and welfare. *American Economic Review,* 66(2): 407-414.

Stephan, P. E. 1996. The economics of science. *Journal of Economic Literature,* 34(3): 1199-1235.

Stephan, P. E. & Levin, S. G. 1992. *Striking the mother lode in science : The importance of age, place, and time.* New York: Oxford University Press.

Train, K. 2003. *Discrete Choice Methods with Simulation*. Cambridge: Cambridge University Press.

Train, K. & McFadden, D. 1978. The goods/leisure trade-off and disaggregate work trip mode choice models. *Transportation Research,* 12: 349-353.

Turner, L. 2003. *La recherche publique dans la production de connaissances, contributions en économie de la science.* Doctoral dissertation. Université Paris 1 Sorbonne.

Turner, L. & Mairesse, J. 2002. Mesure de l'intensité de co-publication dans les réseaux scientifiques et évaluation du rôle de la distance géographique. *Revue d'Economie Politique,* 114(2): 223-243.

Usher, A. & Cervenan, A. 2005. *Global Higher Education Rankings 2005*. Toronto: Educational Policy Institute.

Vandenbroucke, F. 2005. *De financiering van het hoger onderwijs. Voorstel aan de werkgroep financiering. Conceptnota v4, 10-10-2005*. Vlaams Ministerie van Onderwijs.

Vandenbroucke, F. 2005. *De financiering van het hoger onderwijs: voorstel aan de werkgroep financiering. Vervolgnota en simulaties*. Vlaams Ministerie van Onderwijs, from http://www.ond.vlaanderen.be/hogeronderwijs/Vervolgnota9-12-05.htm.

van der Ploeg, F., Veugelers, R. 2007. *Higher education reform and the renewed Lisbon strategy: Role of member states and the European Commission*. CESIfo Working Paper 1901.

van Heffen, O. & Lub, A. *Higher Education in Flanders. Country Report. 2003*. CHEPS - Higher Education Monitor.

Vlaamse Regering, 2007. *Voorontwerp van decreet financiering hoger onderwijs. Memorie van toelichting.* From http://www.ond.vlaanderen.be/hogeronderwijs/beleid/Financiering/default.htm.

Vlaamse Regering, 2007b. *Voorontwerp van decreet financiering hoger onderwijs.* From http://www.ond.vlaanderen.be/hogeronderwijs/beleid/Financiering/default.htm.

Zuckerman, H. & Merton, R. K. 1971. Age, aging, and age structure in science. In N. Storer (Ed.), *The Sociology of Science* (pp.497-559). Chicago: University of Chicago Press.

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